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Report 221

Quaternary Geology of the Precambrian Shield, Saskatchewan

by B.T. Schreiner

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Precambrian Mapping Section

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Foreword

This report is published by the Saskatchewan Geological Survey as one of a series of reports resulting from a four-year program of geoscience surveys under the terms of the Canada-Saskatchewan Agreement on Mineral Exploration and Development in Northern Saskatchewan. This program was supported by funds provided by the federal Departments of Energy, Mines and Resources (25 percent) and Regional Economic Expansion (25 percent), as well as by the Province of Saskatchewan (50 percent).

The work was carried out on contract by the Geology Division of the Saskatchewan Research Council.

The 1:250 000 scale maps are available as Open File Reports OF 84-2 to 84-21. These monochrome maps include marginal notes, augerhole logs, soil profiles and textural triangles. Computer printouts of field and analytical data, as well as sample location maps and computer printouts of the geochemical results, can be inspected at the Saskatchewan Research Council, Saskatoon. These will eventually be made available for viewing and purchase through the Saskatchewan Energy and Mines Data File Series.

R. Macdonald
Assistant Director
Saskatchewan Geological Survey
April 1984

Abstract

The Quaternary geology of the Precambrian Shield area of Saskatchewan was studied on a reconnaissance scale for the purpose of providing a data base for mineral and resource exploration and development, as well as for geotechnical studies, land-use planning, and other terrain investigations.

Three distinct types of bedrock occur in the area: (1) Precambrian basement complex, (2) Athabasca Group sandstones, and (3) Phanerozoic sedimentary rocks. The direction of glacial ice flow was mainly from northeast to southwest, with local variations. Ice erosion and deposition were strongly affected by the bedrock. Rugged local relief occurs on the igneous and metamorphic basement rocks which were differentially enhanced as the glacier eroded low-lying areas and polished resistant knobs. A veneer of sandy till can be found in protected areas and a trellis drainage network is developed on the basement rocks. Thick ground moraine of very sandy till, large drumlins, eskers and outwash deposits occurs in the Athabasca Basin as a result of extensive glacial erosion of the nearly flat-lying sandstone. This terrain has a dendritic drainage pattern. On the flat Phanerozoic sands, silts, clays, limestone and dolomite, less sandy material is found in thick till plains and the terrain exhibits a deranged drainage system.

Sections revealing multiple tills, intertill deposits and till over stratified sediments indicate several ice advances. Striations, grooves, roches moutonnées, flutings and drumlins were formed primarily by the last ice advance. As this ice melted it formed eskers, ice-walled channels, kettles and moraines, all of which are abundant throughout the north part of the area. The Cree Lake Moraine, which crosses the centre of the area from east to northwest, represents the major ice frontal position.

Outwash plains and meltwater channels indicate that glacial waters flowed southward to Lake Agassiz and later northward to Lake Athabasca. Raised beaches, as well as the extent and transgressive onlap sequence of lake sediments, document the invasion and various stages in the retreat of Lake Agassiz. Similar features to the west indicate the contemporaneous occurrence of Glacial Meadow Lake which drained to the Clearwater River. Strandlines cut into drumlins and hills around Cree Lake signify that Glacial Cree Lake occupied this isostatically depressed basin. Rebound caused lake waters to spill south to the Mudjatik River channel and later north to the McFarlane-Snare channel and several other drainage ways.

Glacial Lake Athabasca invaded the area around Lake Athabasca as the ice retreated from the Cree Lake Moraine. Strandlines indicate that Glacial Lake Athabasca, which extended to the east as far as Black Lake, had a consistent maximum level of about 305 m. This suggests that isostatic rebound occurred at about the same rate as the ice retreated from the basin. Glacial Wollaston Lake, which occupied the isostatically depressed basin around Wollaston Lake, drained south to Reindeer Lake via the Swan Spillway. When the Fond du Lac River opened the lake drained north into Glacial Lake Athabasca. Scattered raised beaches and some lake sediments indicate that many smaller glacial lakes occurred in the area.

Sand dunes, sand-blasted boulders and loess are remnants of strong eolian activity which occurred shortly after ice retreat. Permafrost persists in peat landforms which are developed in low-lying areas. Lake ramparts and beaches are found along the shores of many of the modern lakes. The various soil profiles are developed primarily in response to the nature of the surficial parent material.

Keywords: Quaternary geology, Precambrian Shield, northern Saskatchewan, reconnaissance mapping, geomorphology, landforms, surficial deposits, stratigraphic sections, grain-size analyses, deglaciation history, postglacial features

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221A. Quaternary Geology of the Precambrian Shield, Saskatchewan, scale 1:1 000 000 ..... (back pocket)

Introduction

Scope of Survey

This report describes the Quaternary geology of the Precambrian Shield area in northern Saskatchewan, based upon a six-year reconnaissance survey undertaken between 1974 and 1980. The project was contracted to the Saskatchewan Research Council (SRC) by the Saskatchewan Geological Survey using funds allocated under Canada-Saskatchewan Agreements on Mineral Exploration and Development, Geoscience Surveys. The objective of the survey was to provide a data base for mineral and resource exploration and development. The surveyed area covers the entire Precambrian Shield in Saskatchewan and includes some terrain underlain by Phanerozoic rocks to the south of the Shield, for a total of about 245 000 km^2(Figure 1).

Previous Work

The present survey is the first overall systematic reconnaissance of Quaternary geology in the area. Earlier workers, mainly concerned with mapping the bedrock geology, pointed out and described in various detail a number of important features contributory to this survey. Various aspects of the Quaternary geology, and in particular the deposits, landforms and history of the several glacial lakes which affected the area, were discussed by Tyrrell (1893, 1896), Tyrrell and Dowling (1896), McInnes (1913), Johnston (1916, 1946), Cameron (1922), Taylor (1960), Craig (1965), Kupsch (1969), Langford (1977) and Johnston (1978). Elson (1967) has summarized much of the earlier work and given an account of the history of Lake Agassiz.

Moss and St. Arnaud (1955) described the "Grey Wooded" soils typical of northern Saskatchewan; Brown (1965, 1967) studied the occurrence of permafrost in Saskatchewan and Manitoba; and Mott (1966, 1967, 1969, 1973) discussed the Quaternary palynology of central Saskatchewan based on the study of lake sediment cores.

The glacial geology of Canada (Prest et al., 1968) and the ice frontal positions of the retreating Wisconsinan ice sheet (Prest, 1969) have been compiled at a scale of 1:5 000 000. Prest (1970) has also summarized the Quaternary geology of the various regions of Canada.

More detailed studies have been carried out on the Quaternary geology of the Cree Lake area (Sproule, 1939), parts of the Churchill River drainage basin (Kupsch, 1975; Langford, 1975; Johnston, 1978), the Wapawekka area (Langford, 1973) and the sand dune fields south of Lake Athabasca (David, 1977a, b; Smith, 1978). Schreiner (1983) described the features and history of Lake Agassiz in Saskatchewan.

Present Survey

Allocation of Work

The program was headed by E.A. Christiansen (1974-1977) and B.T. Schreiner (1977-1980). Mapping was carried out by four geologists. S.J. McNamara mapped the Phelps Lake area (NTS 64 M) and compiled much of the geology in the other map areas. D.W. Alley mapped the Reindeer Lake South area (NTS 64 D) and the east half of the Lac la Ronge area (NTS 73 P). E.A. Christiansen mapped the Amisk Lake area (NTS 63 L) in conjunction with W.K. Head (Saskatchewan Institute of Pedology), who provided information on surficial sediments south of the Shield. E.A. Christiansen also examined a number of other sites scattered throughout the southern part of the study area, primarily in the Lac la Ronge (NTS 73 P) and Pelican Narrows (NTS 63 M) areas. The present author was responsible for mapping the remaining map sheets in the study area (Figure 1).

D.F. Acton and G.A. Padbury (Saskatchewan Institute of Pedology) and R.J. St. Arnaud (Soil Science Department, University of Saskatchewan) examined representative soils in the map area. The results of this work are included in Appendix A. A seismic refraction survey was carried out by A.T. Schneider in an attempt to determine the composition and structure of some of the eskers and drumlins, locate the bedrock/drift interface and outline structures in the bedrock. The results of his work are included in Appendix B. P.P. David (University of Montreal) examined the sand dunes and other eolian features which are scattered over the western half of the study area. The results of this work have been published separately (David, 1981a). The program also included sampling of the B horizon of the soil at each investigation site and lake-bottom sediment from the adjacent lake, under the supervision of D.R. Haughton, D.A.W. Lehto and V.J. Sopuck.

The Lac la Ronge area (NTS 73 P) was mapped during the first summer as a pilot study to determine the reconnaissance methods best suited to the program. Detailed work along roads, including augerhole sampling, was supplemented by shoreline investigations around most of the larger lakes. A fixed-wing aircraft was used to investigate the more inaccessible areas. Upon completion of this pilot study, a decision was made to map the remainder of the area using a grid-sampling program with fixed-wing aircraft, and to investigate roads in detail through examination of exposures and augering. A computer-coded note system was developed to provide rapid and standardized recording of data.

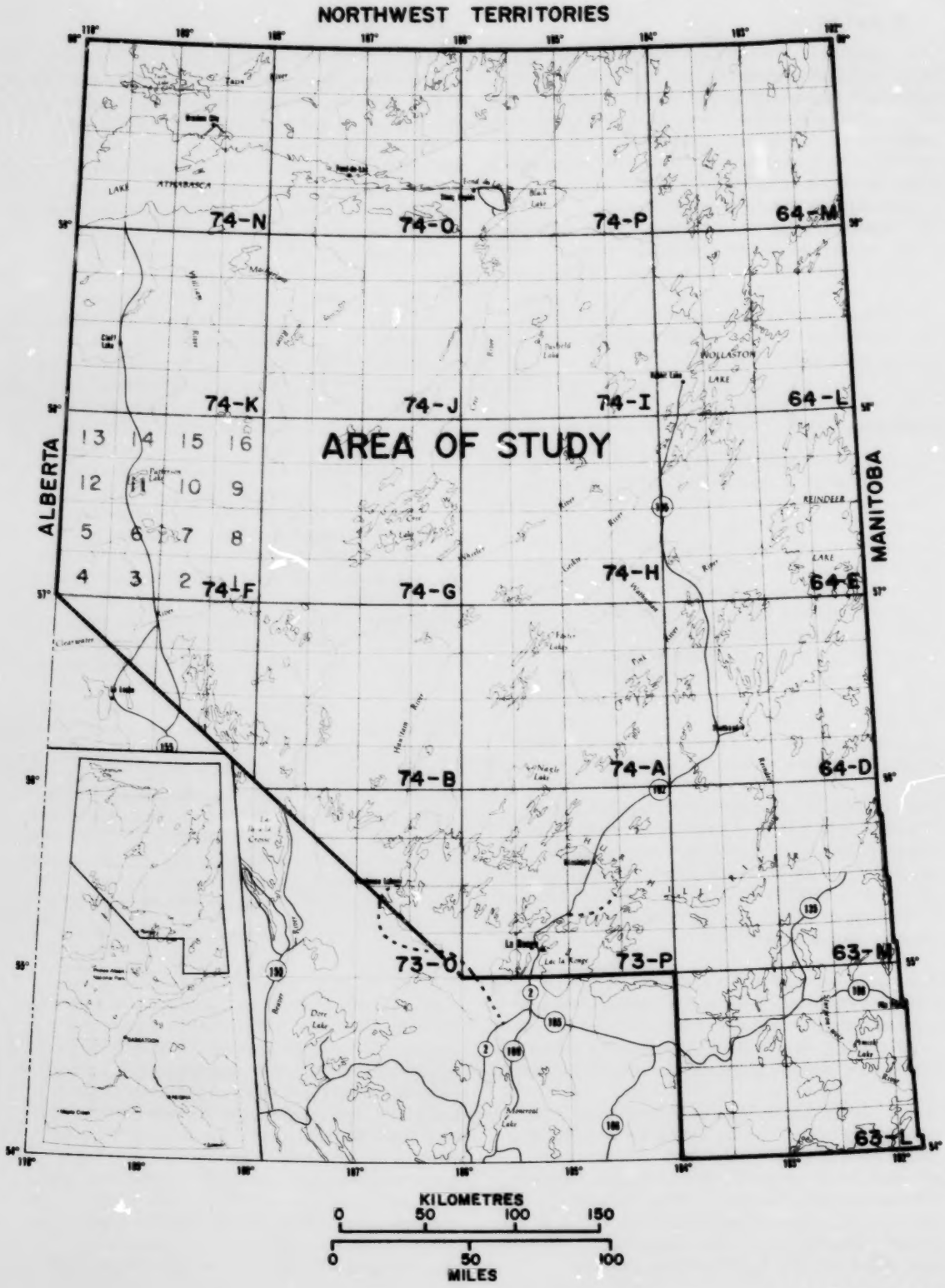

Figure 1. *Location of study area*

Aerial Photograph Study

The field survey was preceded by an interpretation of aerial photographs at a scale of about 1:63 360 and photo-mosaics at a scale of about 1:50 000. Data on bedrock exposure, drift cover and thickness, surface texture, landforms and water features were recorded on photo-mosaics at a scale of about 1:125 000.

Field Investigation

Choice of sites to be studied in the field was based on the airphoto interpretation, ambiguous or confusing geological features being of prime concern. The distribution of sample points followed a grid pattern but was partially controlled by the location of lakes large enough to accomodate float-equipped aircraft. About 150 sites were studied in each NTS area, giving an average density of about one site per 100 km^2. The Lac la Ronge (NTS 73 P) and Reindeer Lake South (NTS 64 D) areas were studied in more detail in order to obtain a better understanding of geologic processes that were operative throughout the Shield. Detailed studies were also carried out along roads and at mining sites, where exposures were more readily accessible. In all, more than 3700 sites were investigated.

At each sample site, a short traverse was made and data concerning the site location, drift units encountered, terrain features and ice-movement indicators were recorded; photographs were taken and, where warranted, diagrams were included on the note form. A sample was taken of each drift unit encountered, from the C horizon (unaltered parent material) wherever possible. Lithology, texture, colour, structure, genesis and age were recorded at the sample site. Lithology, texture, sorting, roundness, carbonate content and Munsell colour (in both the dry and wet state) were determined in a field laboratory. A sample of the B horizon (i.e. zone of accumulation) was collected for geochemical analysis. A lake sediment sample was collected at each site using a torpedo-like sampler modified after the one described by Hornbrook and Garrett (1976).

During the shoreline investigations, stops were made to provide more detailed information where drift exposures or glacial features were apparent; traverses were made inland to investigate particular glacial features, such as raised beaches. Extensive work was done along the roads in the study area (Figure 1). Exposures and borrow pits provided valuable sections, commonly displaying multiple drift units. The roads also provided access for a truck-mounted power auger (Plate 1) used to drill 97 holes to an average depth of 9.6 m. The stratigraphic sections were recorded on lithologic strip logs. Samples of organic material were collected by hand augering in peat bogs.

Sampling and Analysis

The normal sampling depth for surficial sediments was about 1 m, but varied depending on the difficulties encountered in penetrating the drift with a shovel or hand auger. In many places, there is less than 1 m of drift overlying bedrock, so it was not possible to maintain the standard sampling depth. At a few sites, such as augerholes and exposures in road cuts and borrow pits, samples were collected at depths up to 36 m below the ground surface. Augerholes and exposures also made it possible to sample several superimposed drift units.

Each sediment sample was described in the field, after which the material was bagged, numbered and returned to the field laboratory. After a small portion of each sample had been separated for visual inspection and description of lithology, texture, sorting, roundness, carbonate content and wet and dry colour (according to the Munsell colour charts), they were dried, packaged and sent to the sedimentary laboratory of the Saskatchewan Research Council for grain-size and mineralogical analysis. Grain-size analyses were made on all samples from a map sheet except those with a high density of sample points (Lac la Ronge, NTS 73 P; Reindeer Lake South, NTS 64 D), for which only representative samples were analyzed. When a large number of samples was collected from an augerhole or when drift units were homogeneous and easily identified, only selected samples were analyzed.

All drift samples were sent to the SRC sedimentology laboratory for grain-size analysis to determine the silt and clay content. The sand component was separated by sieving and subdivided into five fractions, following procedures established by the United States Department of Agriculture (1951).

The sediment was separated into sand (2.0 to 0.05 mm), silt (0.05 to 0.002 mm) and clay ($<$0.002 mm) size fractions. Silt and clay were determined using the pipette method or an automated particle-size analyzer (Ross, 1979). Sand, obtained by sieving, was subdivided into very fine (0.05 to 0.10 mm), fine (0.10 to 0.25 mm), medium (0.25 to 0.5 mm), coarse (0.5 to 1.0 mm) and very coarse (1.0 to 2.0 mm) fractions, again by sieving. A cumulative curve for the total sample was plotted, as well as cumulative and distribution curves for the sand fractions. The curves were used to classify the sediment according to grain size. The final sample classification was given following verification of the field and field laboratory descriptions. X-ray diffractograms were run on samples with a combined silt and clay content of greater than 25 percent.

The surficial sediments are divided into tills, sand and gravel, sand, silt and clay. The till is generally sandy, but silt or clay can be the most significant component

on a local scale. Tills are classified as sandy, silty or clayey depending on the dominant grain size. Two types of sandy till can be distinguished: a sandy till derived from rocks of the Precambrian basement and occurring in the eastern half of the map area, and a very sandy till derived from sediments of the Athabasca Group in the western half of the area. Sand and gravel deposits and sand deposits were differentiated primarily in the field because the samples collected were not large enough for gravel separation.

Some samples from peat bogs plus other organic materials were sent for radiocarbon dating.

All B horizon soil and lake sediment samples were described in the field and analyzed for a variety of elements according to the system described by Haughton and Smith (1974).

Data Processing

All data recorded on the computer-coded field cards were processed to provide a printout listing the parameters and giving a basic interpretation of the results, namely a classification of the sample and the surficial environment at the site. Information which was not coded, such as photographs, diagrams, lithologic logs and particle size distribution curves, has been kept on file at the SRC as reference material.

Open File Maps and Data

The Quaternary geology for each of the twenty NTS areas has been compiled at a scale of 1:250 000 (Schreiner, 1984). Each map unit is generally a complex of materials, morphologies and drift thicknesses, and is represented by a compound symbol following the system described by Grant (1973) and Fulton et al. (1975). Each map includes marginal notes, augerhole logs, soil profiles and textural triangles. Computer printouts of field and analytical data, as well as sample location maps and computer printouts of the geochemical results, can be inspected at the Saskatchewan Research Council, Saskatoon. Eventually these will be made available for viewing and purchase through the Saskatchewan Energy and Mines Data File Series. A compilation map at a scale of 1:1 000 000, which summarizes the regional surficial geology, is included with this report (back pocket).

Throughout this report, all references to site numbers (e.g. BS-394) pertain to the relevant 1:250 000 scale map and computer data file.

Acknowledgments

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Bedrock Geology

The study area lies within the Churchill Structural Province of the Canadian Shield (Stockwell et al., 1970). Precambrian basement rocks underlie the northern, southern and eastern parts of the area, while the sedimentary rocks of the Athabasca Group occur in the central and western parts (Figure 2). Some of the Quaternary mapping was carried out over the Phanerozoic sedimentary rocks which lie immediately south of the Shield margin.

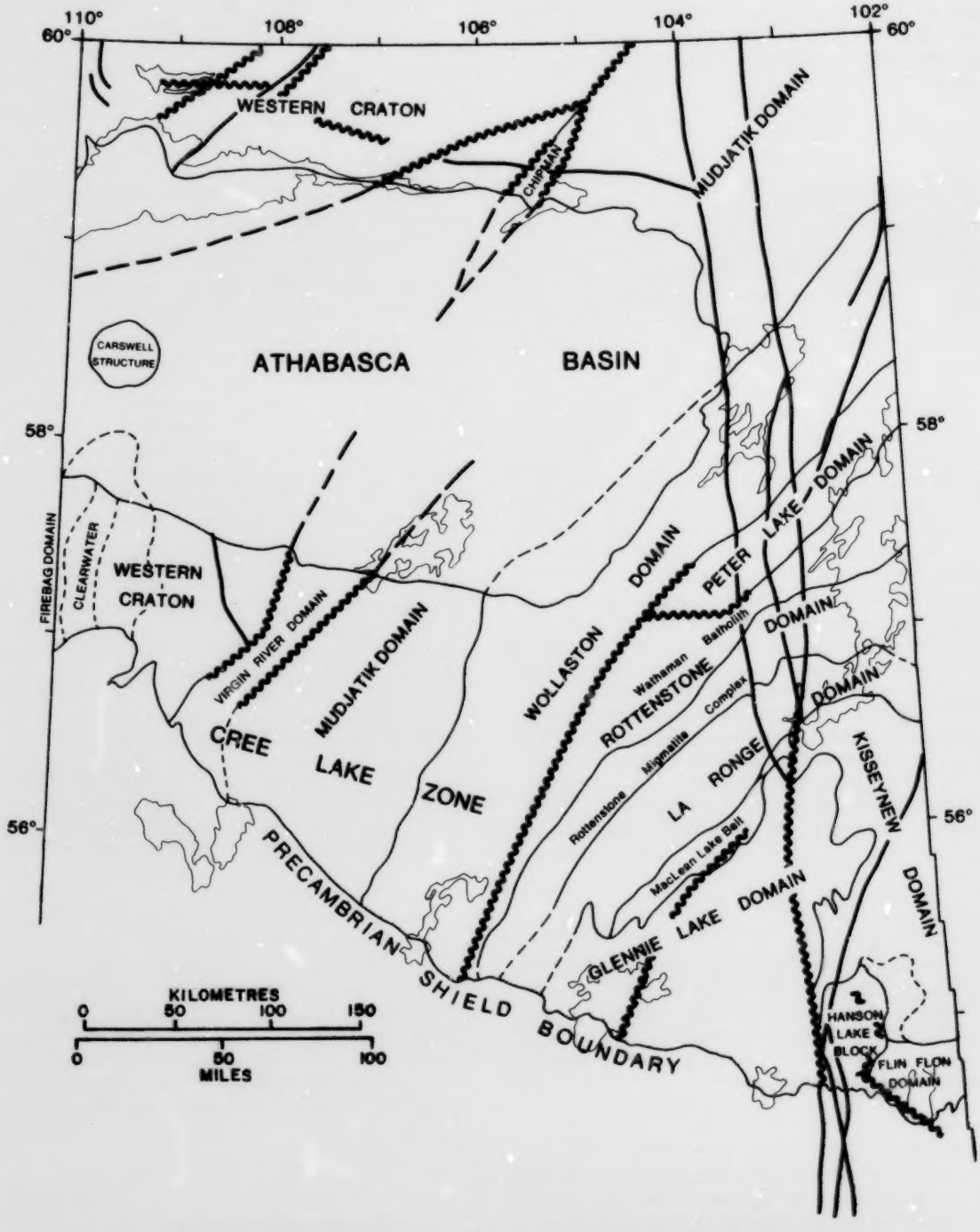


Figure 2. Domains and generalized bedrock geology of the Saskatchewan Precambrian Shield

Precambrian Basement

The Precambrian basement consists of metamorphosed igneous, volcanic and sedimentary rocks. Pronounced northerly or northeasterly topographic trends south of the Athabasca Basin reflect the structural pattern in the basement (Figure 2). North of the Athabasca Basin, these linear trends are less pronounced. The Precambrian geology has been compiled by Macdonald and Broughton (1980) and the rocks divided into crustal units and lithostructural domains by Lewry and Sibbald (1977) and Lewry et al. (1978).

Athabasca Group

The Athabasca Group is a thick, relatively flat lying succession of unmetamorphosed Late Precambrian sedimentary rocks which unconformably overlies the Precambrian basement. The succession forms an oval-shaped basin which dips at a low angle toward the center, where it attains a maximum thickness of about 1.5 km (Hobson and MacAulay, 1969). The stratigraphy of the Athabasca Basin is described by Ramaekers (1979). The Athabasca Group ranges from a conglomerate at the base to sandstone with clay and silt interbeds toward the top (Ramaekers, 1975). It varies from strongly to weakly cemented and from nonhematized to deeply hematized in some portions. The basin is faulted, with the basal contact showing displacement of up to 100 m (Ramaekers, 1979). These faults are associated with shear zones in the basement. The present eastern and northeastern margins are erosional. Boulders and outliers of Athabasca sandstone at Hidden Bay (Ramaekers, 1976) and Reilly Lake (Lewry, 1976) indicate that, at one time, the group extended farther east (Ramaekers and Dunn, 1976). The deposits are dated at about 1350±50 Ma and their origin is attributed to fluviatile deposition by braided streams (Ramaekers and Dunn, 1976).

In the west-central part of the basin, between Cluff Lake and Carswell Lake, there exists a 'window' or absence of Athabasca sediments, revealing a circular patch of Precambrian basement rocks. These are encircled by a ring of dolomites known as the Carswell Formation. This unusual rock sequence, which is highly structurally deformed, is thought to be the result of a meteor impact event.

Phanerozoic Rocks

Phanerozoic rocks of the Williston intracratonic basin overlap the Precambrian basement from the south. Sandstones of the Winnipeg Formation and dolomites and limestones of the Red River Formation (both of Ordovician age) are the overlying rocks along the southeastern quarter of the Shield margin (Macdonald and Broughton, 1980). Along the remainder of the margin in central and western Saskatchewan, the overlying rocks are mainly sandstone, siltstone and mudstone of the Lower Cretaceous Mannville Group (Macdonald and Broughton, 1980). Cemented zones, carbonaceous zones and thin coal beds are also found in these deposits.

According to Lewry and Sibbald (1977), the Phanerozoic rocks extend farther north and west onto the Shield in the extreme western part of the province (Figure 2). This revision presumably places Cretaceous rocks on the Athabasca Group in the vicinity of Patterson Lake. Southeast of the Clearwater River, they have relocated the boundary somewhat further to the east (Macdonald and Broughton, 1980) than Whitaker and Pearson (1972).

Physiography

Physiographic Regions

The study area lies almost entirely within the extensive Kazan Region (Bostock, 1970), which covers most of the northwestern Precambrian Shield (Figure 3). The surface expression in all of the physiographic regions is strongly controlled by bedrock lithology and structure. The Kazan Region in Saskatchewan is divided into the Kazan Upland, which roughly coincides with the crystalline basement rocks, and the Athabasca Plain, which is underlain by the sedimentary rocks of the Athabasca Group. The narrow section underlain by Phanerozoic rocks along the southern margin of the study area lies within the Interior Plains Region, which borders the Kazan Region to the south (Figure 3).

Interior Plains

In the eastern part of the map area, the Interior Plains Region is dominated by the poorly drained Lake Agassiz basin, which forms the Manitoba Lowlands. The elevation ranges from 260 to 335 m, with only minor local variation in relief. The relatively flat lying dolomites, limestones and shales are masked by a thin, discontinuous cover of lacustrine silts and clays or till deposits. Strandlines of Lake Agassiz, as well as drumlins and a few other glacial and recent features, interrupt the otherwise featureless landscape. In the western part of the area, the Interior Plains are higher in overall relief, ranging between 450 and 600 m with some points as high as 730 m. Lacustrine deposits, till and outwash cover most of the flat-lying Mesozoic bedrock. Extensive areas of muskeg are common, and the round to oval-shaped lakes with smooth shorelines contrast markedly with the irregular appearance of lakes found on the Shield (Kupsch, 1975).

Athabasca Plain

The Athabasca Plain is developed on the sedimentary rocks of the Athabasca Group, which are relatively flat lying with some surface expression of faults and fractures. Within the study area, the bedrock is almost entirely covered by a mantle of glacial drift in the form of ground moraine, outwash plains and lacustrine plains. Elevation of the Athabasca Plain ranges from 485 to 640 m; local relief of 30 to 60 m is due mainly to the occurrence of drumlins, eskers and meltwater channels. The sandy glacial deposits give rise to a strongly rolling terrain, where jack pine dominates the forest areas but spruce and poplar are also common. Open parkland is commonly found on the uplands, whereas muskeg occurs in lower lying areas.

Kazan Upland

The Kazan Upland is developed on crystalline Precambrian basement rocks. The topography of the area is typical of the Canadian Shield, with extensive areas of rock that form broad, smooth uplands and lowlands. The landscape results in a monotonous, nearly planar skyline (Plate 2). In detail, however, the surface is extraordinarily uneven; local relief can be as much as 90 m, but is generally less than 60 m. Lakes, swamps and muskeg fill the valleys and depressions between the ridges, hills and knolls. The area around Uranium City has the most rugged topography, with several hills rising more than 100 m above lake level.

A definite relationship exists between topography and bedrock lithology and structure in this region (Alcock, 1920; Ambrose, 1964; Kupsch, 1975). First-order relief is smooth and gently rolling, with the surface sloping gradually to the northwest and southeast from a central highland around and west of Cree Lake. Elevations decrease from 550 m in the central part around Cree Lake, to 300 m in the southeast around Amisk Lake and to 275 m in the northwest around Lake Athabasca.

The very intricate second-order relief consists of a complex series of ridges, valleys and shallow basins. Folding, faulting and fracturing of the rock is responsible for much of this relief, whereas other ridges and valleys are related to differential erosion of the various rock units. Glacial ice subsequently scoured out low-lying areas, especially in zones of more easily eroded rock, thus enhancing the relief. The ice smoothed and polished the faces and crests of resistant bedrock knobs and hills, while simultaneously plucking rock from the lee sides. The direction of ice movement was generally parallel to the regional trends in bedrock structure and lithology. The ice sheet therefore 'etched' and smoothed bedrock features which were originally much more rugged. Some of the bedrock relief has been masked by overburden, particularly in areas of thick drift south of the Athabasca Basin in the western part of the study area. However, the bedrock relief is usually discernible only through a thin veneer of glacial material.

Drainage

The study area straddles the divide between two major drainage systems. The southern and eastern parts drain east to Hudson Bay via the Churchill and Nelson Rivers. The northwestern part drains north to the Beaufort Sea by way of the Athabasca, Slave and Mackenzie Rivers. Eight drainage basins are included in the area (Figure 4).

The development of drainage on the Shield through geologic time is discussed in detail by Robertson (1978). The present drainage pattern is strongly influenced by bedrock in northern Saskatchewan. Where Paleozoic and Mesozoic rocks occur, poorly

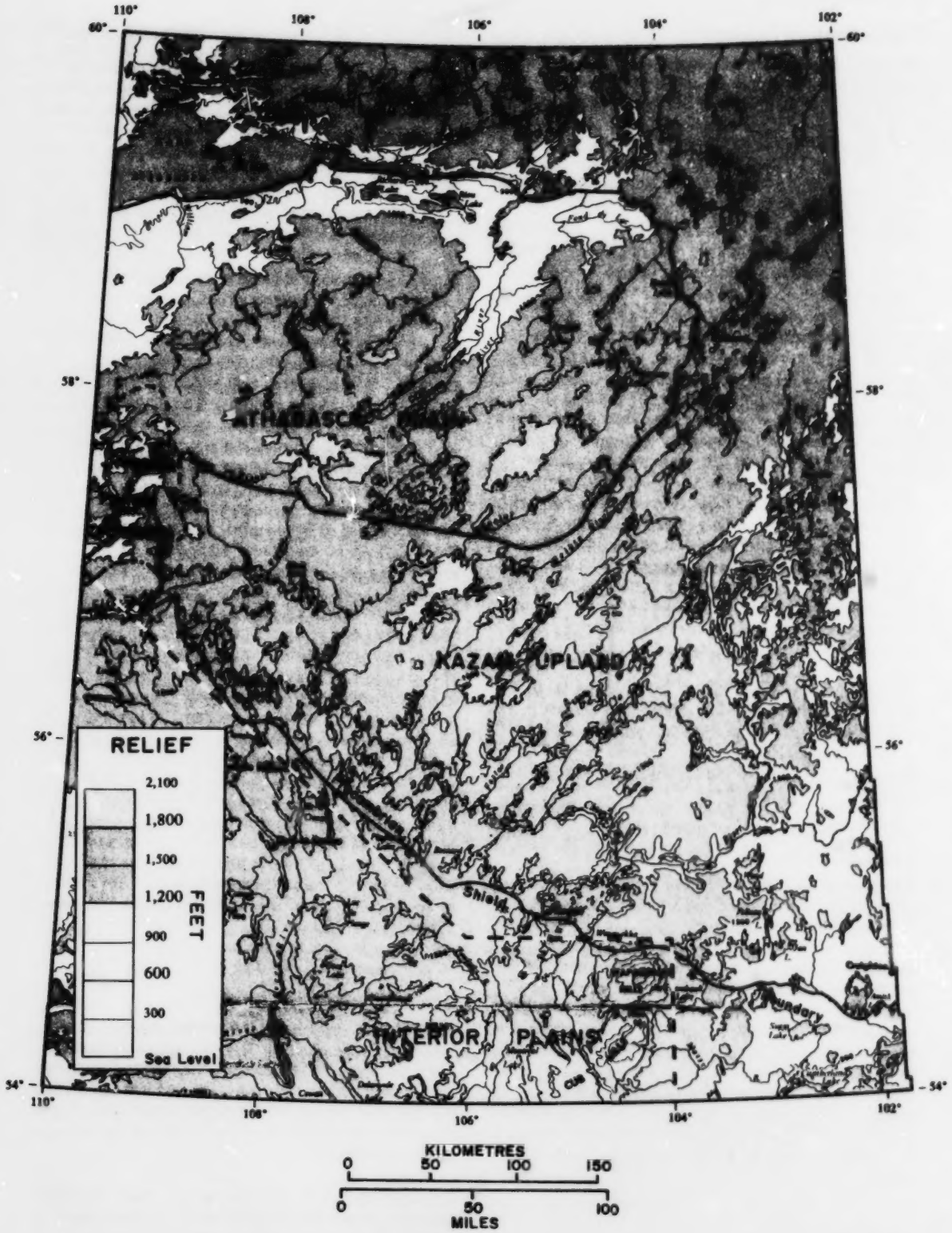


Figure 3. *Physiographic regions of northern Saskatchewan (modified from Acton et al., 1960; Richards and Fung, 1969; Bostock, 1970). Contour interval 300 feet*

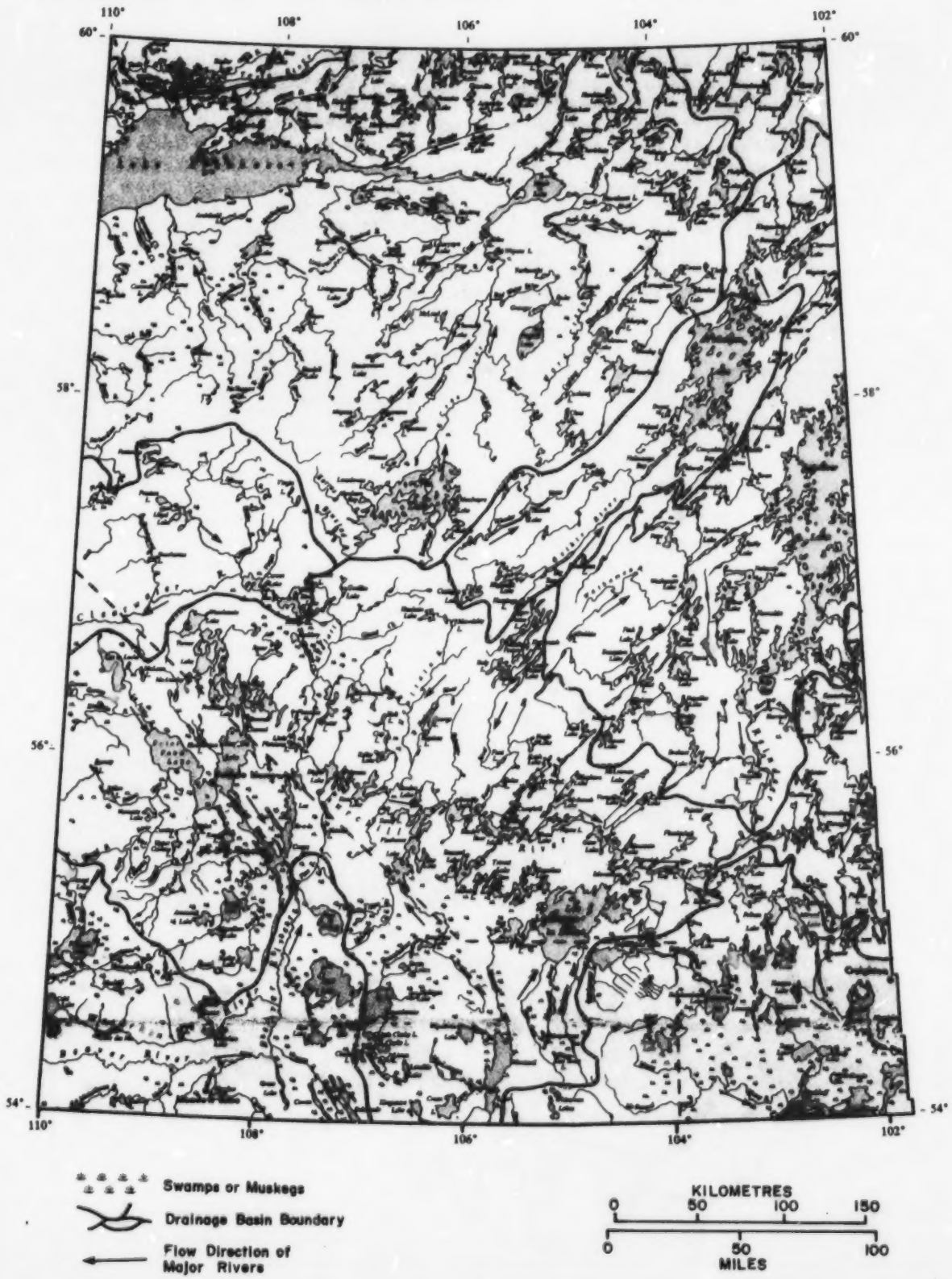


Figure 4. Drainage basins of northern Saskatchewan (after Richards and Fung, 1969)

integrated drainage prevails. Large areas of muskeg cover this flat-lying terrain. The rivers have low gradients and most lakes are large and round or oval in outline, with smooth shorelines. In contrast, the Shield area exhibits long, narrow, ragged lakes which generally parallel the bedrock structure. The Churchill River provides excellent examples of both these contrasting patterns, since it traverses the Interior Plains as well as the Shield. It consists of a series of long, narrow lakes linked by fast-flowing rivers with rapids and falls. The lakes are oriented parallel to bedrock structure and the direction of ice movement. This typical pattern is most pronounced south of Lake Athabasca, the Fond du Lac River and Black Lake. It results in a trellis-like drainage pattern, with many rivers flowing parallel to one another in a northeast-southwest direction. Connecting these rivers are short streams, generally at right angles to the major rivers and following joint patterns or other weaknesses in the bedrock. Perched bogs are numerous but generally small in area. As much as 35 to 40 percent of the Shield area may be covered by water.

The relatively even, drift-covered surface of the Athabasca Plain has a dendritic drainage pattern. Muskeg is common, especially in the western part where it covers some large areas.

In some places, overburden has influenced the drainage pattern. Damming of lakes by glacial deposits occurs, especially on the north side of the Cree Lake Moraine. This pronounced, extensive end moraine forms the southern shore of several lakes (e.g. Nagle, Black Birch and Patterson Lakes). Drumlins and eskers may cause the stream system to be diverted around them, especially in the case of eskers, which generally occupy valleys or original drainage courses such as along the Geikie River (Figure 4). Fluvial deposits, such as outwash sands and gravels, are commonly located in former meltwater channels. Sandy fluvial deposits host meandering misfit streams occupying enlarged valleys (e.g. the Haultain and Mudjatik Rivers). The Williams River also meanders extensively, especially near Lake Athabasca where it crosses the fine sandy deposits of the former glacial lake. Kettle lakes (small, deep, commonly circular depressions) are generally found in sandy or gravelly deposits. These isolated depressions, formed by melting of buried ice blocks, are generally not connected by surface drainage channels.

Soils

The soils of the Precambrian Shield in northern Saskatchewan belong to the "Dominantly Podzolic Soil Zone" (Clayton et al., 1977). Prior to this study, little work had been done on soils covering the Shield. A number of profiles were sampled by D.F. Acton, G.A. Padbury and R. St. Arnaud as part of the Quaternary mapping program. The results, presented in Appendix A, provide the basis of soil information within the study area. Typical soil profiles are shown on the 1:250 000 scale Quaternary maps (Schreiner, 1984).

Glaciation in Northern Saskatchewan

Continental glaciers advanced and retreated across the Precambrian Shield in northern Saskatchewan several times during the Quaternary Period. The repeated glaciations resulted in erosion of the bedrock and any previously deposited glacial sediments, and the deposition of ice-laid tills and water-laid gravels, sands and silts.

Generally, the last glacial advance in a given area obliterates many of the effects and deposits of earlier advances. The last major ice mass to have affected northern Saskatchewan was the Laurentide Ice Sheet (Figure 5).

An ice sheet records its direction (and sometimes sense) of movement through striations, grooves, gouges and crescentic marks etched into the rock surface (Plate 3) and by moulding its drift into streamlined forms. Streamlined bedrock features are common in the eastern half of the map area where the drift cover is thin. Streamlined drift landforms such as drumlins and flutings indicate direction and sense of ice movement in the western half of the study area, where the drift is thicker and striations are rare. A few flutings and drumlins are found in the east, but only in areas of thicker drift. These landforms will be discussed later in more detail.

During deglaciation, the ice flowed radially from the Keewatin Centre, resulting in a dominant southwesterly flow direction across the study area (Figure 6). The direction ranges from 200° near the eastern provincial boundary to about 245° on the western boundary, with a direction of about 270° indicated south of the Fond du Lac River (Figure 7).

Although the dominant southwesterly direction is maintained throughout the area, there are local variations. Johnston (1978) noted west- to northwest-trending glacial striae at several localities in the southern part of the Reindeer Lake area. He felt that these striae are older than the southwesterly-trending ice movement indicators but were formed by the last glaciation. These striations may have formed during the advance of the glacier, whereas the younger ones formed during retreat.

Schreiner and Alley (1975) encountered striations along Highway 102 near McLennan Lake. The strongly developed striae trend between 200° and

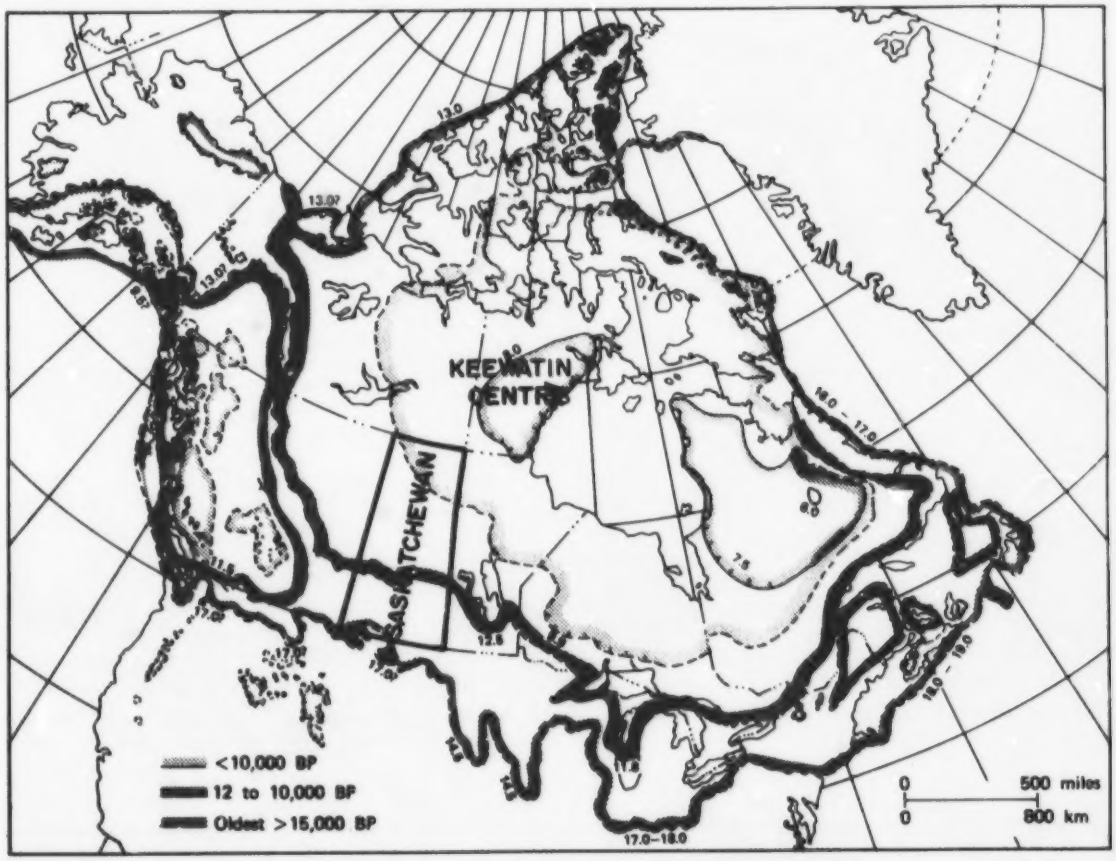


Figure 5. Extent of the continental Laurentide Ice Sheet (modified from Flint, 1971)

225°. The finer, more weakly developed striae cut across the first set at directions ranging from 245° to 260°, with a maximum divergence at 290° and 310°. The origin of these later striae is not clear, but they may be related to a minor readvance of a thin ice lobe into the Lake Agassiz basin (Schreiner and Alley, 1975) or they may have formed in the manner proposed by Johnston (1978). Striations and flutings were noted on the north side of and atop the Cree Lake Moraine in the eastern part of the study area, indicating that ice may have advanced up to and over the moraine in some places.

Ice movement features along the southern part of Reindeer River indicate a southerly ice flow. Other minor variations are noted in many areas and can usually be attributed to an irregular bedrock surface. Ice is deflected or directed by valleys and uplands, resulting in a 'wandering' pattern of ice movement.

In the Cluff Lake area, flow direction changes from southwest to south to nearly southeast within a distance of about 10 km. This rapid deflection is attributed to a thin lobate ice front which fluctuated back and forth as the ice retreated from the Cree Lake Moraine.

South of Black Lake and the Fond du Lac River, drumlins indicate a direction of ice movement from east to west. This strongly developed flow direction must have formed in response to the Lake Athabasca basin to the west. On the north side of the river, a few striations indicate ice movement in a southwesterly direction.

The age of eroded ice-movement indicators is difficult to determine. Because glacial erosion would likely obliterate most previously formed striations and grooves, the striae seen in the field probably represent the last glaciation. Such is also the case for most drumlins and flutings.

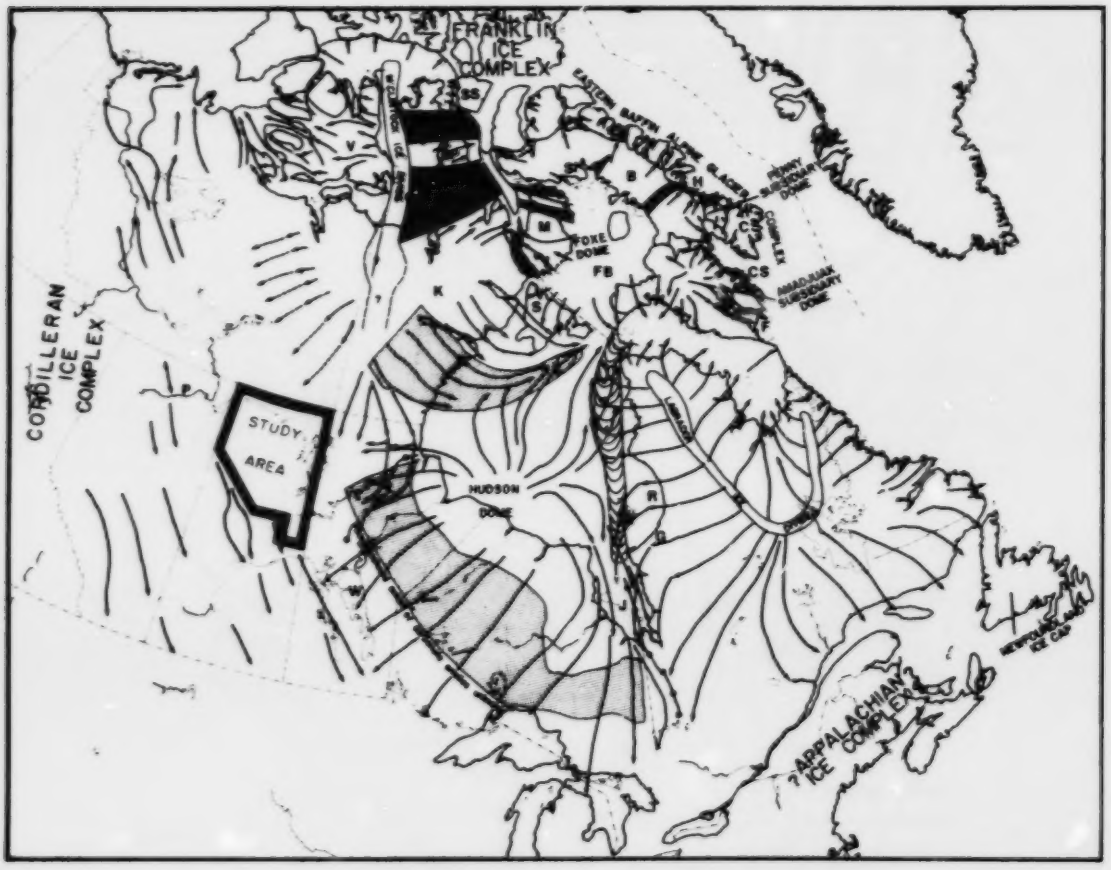


Figure 6. *Structure and dynamics of the Laurentide Ice Sheet during the Late Wisconsinan maximum (modified from Dyke et al., 1982)*

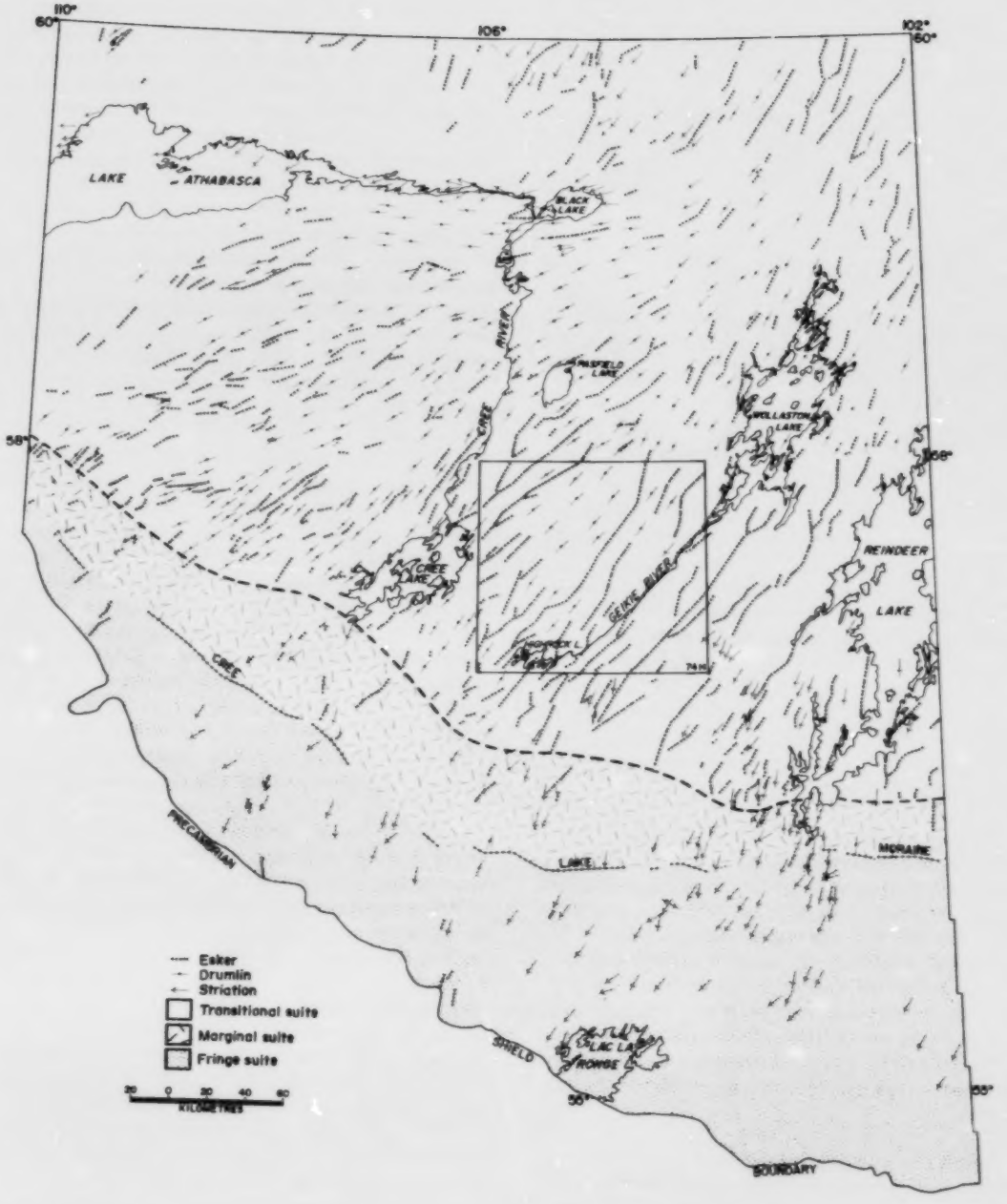


Figure 7. *Eskers, drumlins and striations in northern Saskatchewan; transitional, marginal and fringe suites (Clayton and Moran, 1974) are shown; striations and drumlins indicate the general flow pattern of the ice*

Erosion

Preglacial Erosion

The erosional history of the Saskatchewan Precambrian Shield area through geologic time has been reviewed and interpreted by Robertson (1978). Weathering and subaerial erosion by mass movement and streams reduced the mountains built during the Hudsonian Orogeny to an erosional plain of low relief (Ambrose, 1964). In certain areas, this erosional surface was down-warped and shallow waters and migrating streams filled the depression with the sands and gravels of the Athabasca Group. The original areal extent of these clastic sediments was probably much greater than at present. Outliers have been discovered beyond the present margin of the Athabasca Basin (Ramaekers, 1976). One large outlier near Reindeer Lake (Lewry, 1976) is located about 95 km southeast of the basin.

Weathering was again active prior to deposition of the Phanerozoic sediments, and more of the sandstone would have been eroded during this interval. Phanerozoic rocks, particularly Ordovician dolomites, may have covered most of the Shield prior to erosion (Ambrose, 1964).

Glacial Erosion

There is disagreement concerning the proportions of the Phanerozoic cover eroded prior to and during glaciation. Ambrose (1964) came to the conclusion which was restated by Kupsch (1975, p.18) that "the present surface of the Shield was produced by steam erosion long before glaciation", while White (1972, p.1037) felt that "glaciation skinned Paleozoic rocks off the crystalline basement".

Christiansen (1971) has attributed the source and composition of the tills in southern Saskatchewan to glacial stripping of sedimentary rocks overlying the Shield. The lower, older tills contain more clay and less carbonate than the upper, younger tills. Presumably the lower tills were derived by glacial erosion of the clay-rich Upper Cretaceous rocks which were more extensive prior to glaciation than at present. Dolomites and limestones underlying the Cretaceous strata were then exposed and successive glacial advances incorporated more carbonate into the tills.

Tills from the Shield, sampled during the present study, contain no carbonate minerals. Also, no Phanerozoic erratics or outliers were noted in the study area. These observations, however, do not prove that Paleozoic or Cretaceous rocks were absent from the Shield prior to the first glaciation. Most of the tills sampled lie near the surface and likely represent the last glacial advance. Earlier glacial events could have removed the sedimentary rocks and deposited the debris farther south. Further investigations on the Shield and in southern Saskatchewan, especially in stratigraphy, may answer this question.

The major effect of glaciation on the Precambrian rocks was undoubtedly the severe erosion which modified the surface to its present appearance. The direction of ice movement was nearly parallel to the bedrock structural trend, so that abrasion by the ice enhanced the Precambrian topography by eroding low areas, especially those composed of less resistant rock. Stream valleys were enlarged, particularly those lying parallel to the glacial movement. Resistant hills and knolls were scraped and polished but remained as areas of high relief. Erratics, many perched on outcrops or partially buried in glacial drift, are evidence of the erosion and transport of fragments of bedrock by the ice. Boulder fields or *felsenmeer*, scattered throughout the area in topographically low areas or on crests and sides of hills, may be the result of frost shattering, as will be discussed later.

The ice was particularly effective in eroding the sediments of the Athabasca Group. Large erratics are scattered across the surface of the basin and also down-ice from it. These erratics attest to the quarrying action of the ice sheet. The many large drumlins which cover parts of the sandstone suggest that thick drift was available as the ice advanced and formed these streamlined features. It is difficult to determine the amount of sandstone stripped off by the ice. However, the very thick and sandy drift down-ice from the sandstone (revealed in augerholes, in which till thicknesses commonly exceed 15 m) indicates that large quantities of sandstone were removed and incorporated into the glacial drift.

The glacial drift influenced by the sandstone occurs primarily on or down-ice from the present outcrop of the Athabasca Group. A line projected from the edge of the sandstone near Wollaston Lake in the direction of ice movement (southwest) defines the approximate boundary between drift influenced by rocks of the Precambrian basement and that influenced by the sandstone (Figure 2). Near the Foster Lakes, the drift is thin and discontinuous, with angular rock fragments of mainly crystalline rock. The matrix also contains a wide variety of minerals. To the northwest, around Highrock and Costigan Lakes, the drift is thicker, more continuous and very sandy, and contains numerous sandstone cobbles and pebbles, most of which are subrounded. This significant change in drift occurs all along the projected line and suggests that the southeastern margin of the Athabasca Basin is in roughly the same location as it was prior to glaciation. The effects of glaciation on the northeastern and northwestern edges of the basin were much more severe. The steep rugged escarpments which face up-ice are in part the result of glacial erosion. To the northwest, the edge of the basin is covered by the deep waters of Lake

Athabasca. There is little evidence to suggest that the sandstone extended much further to the north prior to glaciation.

The crystalline rocks of the Precambrian basement in northern Saskatchewan were resistant to erosion by the glacier, so relatively little debris was available for deposition and the till is generally quite thin. The glacial drift is relatively thick around Phelps Lake in the northeastern part of the study area. This increased thickness may be the result of glacial erosion of the finer grained metasediments found in this area.

North of Lake Athabasca and the Fond du Lac River, the drift is extremely sparse and thin, indicating that the ice was not very effective in eroding this rugged bedrock.

Postglacial Erosion

Postglacial erosion has been slight relative to that associated with glaciation. Some chemical and mechanical erosion (mainly frost shattering) has deteriorated bedrock, but these effects are minor and usually involve only pitting or spalling of outcrop surfaces. Surface runoff has cut into the surface sediments, especially fine materials such as silt. This stream erosion, which results in trenches about 1 m in depth, is best seen in ditches along roads in areas of silty deposits from which vegetation has been removed (Plate 4). The eroded sediments are carried to local streams and rivers and then deposited in lakes. During times of high runoff, the Wathaman River is a clear stream until it flows under Highway 102 where it picks up sediment carried into the stream by the ditches. It there becomes silt laden, eventually depositing a delta, outlined by a plume of murky water, in Brabant Lake. Gullying on steep-sided hills, especially large drumlins, is evident in many places (Plate 5). Postglacial rivers, such as the Mudjatik River, have cut entrenched meandering paths into still older postglacial channels. This activity continues at present, causing the migration of meanders and the transport of silty sediment in the streams. The William River is similarly entrenched into primarily glaciolacustrine sediments. This braided, meandering water course carries sediment supplied by the encroaching sand dunes and transports the load to form a delta in Lake Athabasca.

As the ice retreated, meltwater drained away and sediments dried out. Strong winds eroded the sandy sediments, carrying away the finer fractions. These sand-laden winds etched boulders and bedrock, and finally deposited sand dunes and loess, particularly in the area south of Lake Athabasca.

Warming of temperatures during postglacial times resulted in the thawing of permafrost. Peat plateaus and other areas of extensive permafrost deteriorated to small isolated patches of frozen ground and wet muskeg.

Surficial Deposits

Glacial Landforms

Ground Moraine

The dominant landform of glacial origin in northern Saskatchewan is ground moraine. It can be defined as the morphological expression of glacial drift deposited either beneath the glacier by a process of lodgement or from the ice itself by the process of ablation; its relief varies from flat to hummocky. Ground moraine on the Shield is composed primarily of sandy ablation till which ranges in thickness and surface expression, as indicated on the accompanying map (Map 221A, back pocket). It is generally thin and discontinuous in areas underlain by crystalline basement rocks. Lakes, muskegs and bedrock outcrops, which may comprise more than 50 percent of the land surface, dissect the ground moraine into small isolated patches. Its continuity is also interrupted by fluvial deposits, especially those related to eskers and outwash deposits. South of the Shield, the ground moraine is a rolling to hummocky plain composed mainly of finer grained till.

In the southeast, glaciolacustrine silts and clays form a discontinuous deposit which masks the relief of the bedrock or the thin veneer of ground moraine. The surface expression of the ground moraine is a reflection of the bedrock topography. The thin cover of ground moraine and/or lacustrine sediments may modify the rock surface by filling low areas. Map 221A (back pocket) shows the ground moraine south and west of Reindeer Lake as a veneer generally less than 3 m thick. Although augerholes indicate the average thickness of drift to be about 8 m in the eastern half of the map area, much of the material is stratified and is usually underlain by about 1 m of till.

In the northeast, around Wollaston Lake and Phelps Lake, the ground moraine is thicker and more continuous. Moraine plains and drumlinoid moraine are the dominant morphologies. North of Lake Athabasca, the Fond du Lac River and Black Lake, the ground moraine is very thin and sparse. Bare bedrock outcrops predominate and a thin veneer of ground moraine covers low areas between outcrops and occasionally the highland areas.

On and down-ice (southwest) from the Athabasca Basin, the ground moraine is generally thicker and more continuous, and ranges from a veneer to plain and drumlinoid forms. Bedrock outcrops, lakes and bogs are common but less abundant than on the crystalline basement. Outwash sands and gravels, as well as eskers, commonly cover the ground moraine. Augerholes in the western half of the map area reveal that the thickness of the till layer averages about 20 m and ranges up to 37 m. The ground moraine is very sandy and contains numerous quartzite pebbles and cobbles. Relief on the ground moraine overlying the Athabasca Group is due primarily to depositional and erosional processes acting on the drift, rather than being a reflection of the underlying bedrock structure. Faults, shear zones and other structural elements in the bedrock are difficult to distinguish through the glacial cover in this area.

Ground moraine is the result of deposition of subglacial, englacial and superglacial debris by the melting ice mass (Figure 8). The hummocky surface expression results from the melting of buried ice. As discussed in the previous chapter, the thin veneer of till on the crystalline basement rocks indicates that they are resistant to erosion and supplied little material for subsequent deposition. The thick, very sandy nature of the ground moraine overlying the Athabasca Basin indicates that these rocks are easily eroded and therefore supplied the ice sheet with abundant debris.

Cree Lake Moraine

The Cree Lake Moraine is the most prominent and significant end moraine in the area. Flint (1971, p. 200) defined an end moraine as " ... a ridgelike accumulation of drift built along any part of the margin of an active glacier". The Cree Lake Moraine can be traced for about 800 km across the Shield in Saskatchewan east into Manitoba and northwest into Alberta, as shown by Prest et al. (1968) and on Map 221A (back pocket).

The Cree Lake Moraine comprises several different landforms. In the Reindeer Lake South area, it consists of disconnected mounds elongated in an east-west direction south of Kamatsi, Pagato and Harriott Lakes. The rounded, subdued surface of the moraine, as well as a number of flutings on the north side oriented normal to the moraine trend, show that

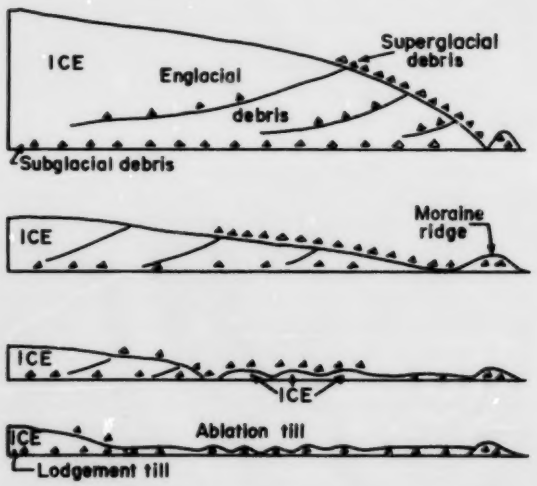


Figure 8. Ground moraine and end moraine (modified from Price, 1973, p. 203)

the end moraine may have been at least partially overridden by ice. Large kettles in the moraine suggest that the deposit is very thick. No visible evidence of the Cree Lake Moraine was detected between the Reindeer River and Brabant Lake. This apparent lack of surface expression conflicts with the findings of Prest et al. (1968) who, on the basis of airphoto interpretation, showed a short section of the moraine in this area which lies within the Agassiz basin. The moraine may have been eroded by wave action or obliterated by sediments, or it may not have been deposited as distinctive end moraine. If the ice margin was floating and calving rapidly in water, the formation of an end moraine would not be expected.

The Cree Lake Moraine reappears west of Brabant Lake as a low relief, nearly continuous ridge about 10 m high. This section, approximately 25 km in length, curves toward the south and becomes an esker-kame complex, terminating in a broad outwash plateau pitted with large kettles. Extending from this point to Jewett Lake, a distance of about 12 km , the moraine is absent. Between Jewett Lake and Nagle Lake, the moraine is a nearly straight, single, narrow ridge of high relief (Plate 6). It rises as much as 35 m above the surrounding terrain when crossing low-lying areas. This section of the moraine terminates to the east at Jewett Lake and to the west at Nagle Lake in fan-like outwash deposits. It resembles a fluvial deposit and may have been formed by water-transported material along the ice front or in an ice-walled channel parallel to the ice margin. The form of this part of the moraine resembles that of the Salpausselkä Moraine in southern Finland, which consists of wide, high-relief ridges and is thought to have formed in fracture zones near the ice terminus (Virkkala, 1963).

From Nagle Lake, the Cree Lake Moraine turns northwesterly. To the south and west of George Lake in the Mudjatik area, the moraine is patchy and hummocky and commonly undetectable from aerial photographs. South of Black Birch, Careen and Lloyd Lakes, the moraine can be easily traced and forms a broad, hummocky band of high relief which may be composed of several interwoven ridges (Plate 7). The height of this section above the local terrain commonly exceeds 45 m, with a maximum height of about 75 m, and it can be up to 2 km in width. Kettles dot the surface of the deposit. Spillways and meltwater channels cut through the moraine in many places and indicate that it acted as a temporary dam, ponding meltwater to the north. The many large lakes now bordering the northern margin of the moraine are probably remnants of these ponded bodies of water.

Southwest of Preston, Forrest and Patterson Lakes, the moraine becomes a series of small, low-relief ridges (Plate 8). These consecutive end moraines are curved and sinuous, indicating that the ice margin in the area was less definite and may have been retreating more rapidly than in other areas.

The Cree Lake Moraine likely represents a major stillstand of ice in northern Saskatchewan (Prest, 1970, Figure XII-15). Prest shows an ice-marginal position which corresponds to the Cree Lake Moraine and dates the front at approximately 10 000 years B.P. This position may represent the front of a remobilized ice mass, since flutings on the moraine indicate that the ice was active north of the moraine.

Other End Moraines

A number of other end moraines have been studied in the map area. All were identified on aerial photographs and some were examined briefly in the field.

Johnston (1978) described a series of end moraines at the south end of Reindeer Lake, south and west of Deep Bay. These features are relatively short, the longest being only 2.4 km. They range in height from 15 to 60 m and are composed of ice-contact material, mainly sand and gravel, which is sorted and bedded in places. Their composition and their orientation perpendicular to a large esker suggest that the deposits were formed along the ice front. Johnston (1978) suggested that the moraines may mark fluctuations of an ice mass which persisted in the Reindeer Lake basin after much of the region was free of ice.

In the Lac la Ronge area (NTS 73 P), an end moraine extends northwest from McIntosh Lake for a distance of approximately 25 km. It is discontinuous over bedrock ridges but can be traced on aerial photographs. The central portion is generally about 25 m above local lake levels (Plate 9). At the only site sampled during this study (BS-394)[1], sandy till was encountered on the surface of the moraine.

A distinct, low relief, sinuous ridge extends from west of Cluff Lake in an arcute path across the south tip of the lake, then curves to the northeast and eventually turns easterly. It can be traced on aerial photographs for a distance of nearly 15 km and resembles an esker in plan. However, the ridge is normal to local ice movement indicators such as drumlins and flutings. It is usually less than 5 m high and generally has a steeper south-facing slope. In two trenches which intersect the ridge, it was found to consist of till intermixed with poorly sorted sand and gravel. The composition and orientation of the ridge indicate that it is an end moraine.

[1]Throughout this report, all references to site numbers pertain to the relevant 1:250 000 scale map and computer data file.

South of Lake Athabasca, similar sinuous end moraines occur west and east of Archibald Lake. One of these, located north of Ens Lake, is 4 to 5 m high and steep sided, with large boulders on the surface; it is oriented transverse to minor flutings which lie to the north. These end moraines apparently formed at the terminus of a thin lobe of ice which may have been either a remnant of the retreating ice or a minor resurgence of the ice.

In the extreme northeast corner of the map area, an end moraine borders Hasbala Lake to the south and west. This broad hummocky band of very sandy drift, formed by debris dumped at the front of a lobe of stagnant ice, represents the last stillstand position of the ice as it retreated from Saskatchewan.

Minor Moraines

Most minor moraines are part of a repetitive sequence of small ridges, many of which have a sinuous plan and are spaced at more or less regular intervals. These features resemble the 'washboard moraines' described by Gravenor and Kupsch (1959). Minor moraines occur in zones in the western part of the map area. A large number are present in the vicinity of Patterson Lake and west of Minto Lake. Numerous minor moraines occur in a zone extending from northwest of Carswell Lake east to the William River. A smaller group is located at the southwestern extremity of Cree Lake, while another zone occurs in a narrow band southeast of Weitzel, Engeman and Mayson Lakes (Map 221A, back pocket).

These minor moraines appear on airphotos as a symmetrical pattern of parallel sinuous ridges of varying heights (Plates 10 and 11). Some of the ridges near Forrest Lake are about 2 m high, have slopes of 8° to 10° and are composed of sandy till covered with boulders. In some places, large single ridges occur with or without groups of smaller ridges. These are about 10 m high, have slopes of 15° to 25° and are composed of till covered with boulders (Plate 12). Most are superimposed on other landforms such as drumlins; the result is a uniform band crossing the other landform, usually at right angles. The boulders on the surface are commonly sand-blasted on their southeastern faces, indicating that sand-laden wind blew from the southeast. Fine eolian silt deposits are locally present between or on the ridges.

The area northwest of Carswell Lake exhibits two types of minor moraines. One group (Plate 13), furthest to the northwest, consists of distinct symmetrical ridges similar to those around Forrest Lake. These minor moraines may cross highland areas, particularly drumlins, but are generally restricted to terrain below 300 m in elevation. The second group of moraines consists of repeating, rounded, linear mounds which are also oriented transverse to the direction of ice movement. Kettles are common in the low troughs between mounds (Plate 14). This pattern resembles the 'swell-and-swale' topography of southern Saskatchewan and Alberta and the 'washboard moraine' described by Gravenor and Kupsch (1959).

The minor moraines around Patterson Lake are interpreted as an extension of the Cree Lake Moraine (Prest et al., 1968). These features probably formed at the ice margin or in crevasse-like cracks parallel to and near the ice margin, where melting released debris that was carried in or on the ice. The rhythmic nature of the moraines suggests a systematic ice retreat, possibly correlative to yearly or longer term cycles. The contrasting patterns of moraines northwest of Carswell Lake may be caused by the presence of Glacial Lake Athabasca. The moraines found below an elevation of 300 m may have developed near the ice front, which was in contact with the glacial lake, while those occurring above the 300 m level formed where the ice was on land. The relationship between the ice front and Glacial Lake Athabasca is discussed in the section on glacial history.

Eskers

Eskers can be defined as sinuous ridges of sand and gravel deposited by ice-contact streams. They tend to conform to bedrock structure and most are parallel to the flow direction of the last ice movement. Eskers commonly cross divides or other obstructions, especially where bedrock structure does not parallel the ice movement direction. An esker may be a single narrow ridge or a braided system of winding ridges. The ridges can be up to 50 m high and range in width from tens to hundreds of metres. A single esker commonly varies considerably in shape and size over its length. Kettles and other melt-out features are commonly found, both on the esker ridge and on the flanks of the deposit.

Eskers are most abundant and well developed in the north-central and northeastern parts of the map area, especially in the Geikie River area (NTS 74 H). This zone of eskers terminates about 35 to 45 km north of and parallel to the Cree Lake Moraine (Figure 7). One esker which follows the Geikie River can be traced for more than 180 km (Plates 15 and 16).

A brief seismic investigation was carried out by A.T. Schneider on an esker which crosses the road about 6.5 km north of the settlement of Black Lake (Appendix B). The total thickness of drift is about 20 m. Loose dry sand and gravel are underlain by saturated sand and gravel which, in turn, are underlain by till in some parts of the esker. There does not appear to be any relationship between the bedrock structure and the formation of the esker.

Ice-contact deposits, commonly sand and gravel, are the main components of most eskers, but medium- to fine-grained sands may also occur, and locally eskers can be entirely composed of subrounded boulders. Transport distance of esker components is variable. Hellaakoski (1930) gave an average transport distance of less than 5 km, while Lee (1965) determined distances ranging from 3 to 13 km for various minerals. Shilts (1973) suggested a maximum distance of 8 km, whereas Virkkala (1958) determined distances greater than 5 km and up to 20 km. These measurements relate to the fluvial transport of material that was previously carried by the ice.

Eskers formed as the last glacial ice thinned and melted from an area. The eskers in northern Saskatchewan appear to be related to the ice mass which was bounded to the south by the Cree Lake Moraine. Eskers were deposited when the ice front had retreated 35 to 40 km to the north of the moraine (Figure 7). This zone, referred to as the 'Transitional Suite' by Clayton and Moran (1974), is the point where meltwater supply, ice thickness, structure and englacial debris were all conducive to esker formation.

Ice-Walled Channels

Ice-walled channels have been described by Gravenor and Kupsch (1959). As the name implies, these features were meltwater channels in the ice and open to the sky; they formed in stagnant ice. Drift in the valley may consist of till or sand and gravel, and almost everywhere is pitted with kettles.

An excellent example of ice-walled channels can be seen near Key Lake (NTS 74 H-4), where a series of southwest-trending bands of outwash is separated by drumlinized moraine (Figure 9). An esker commonly occupies the centre of the channel; hummocky outwash deposits on either side are pitted with kettles. Lakes in the channels form chains of irregular water bodies connected by short streams or muskeg. The channels range in width from less than 1 km to more than 5 km. A deep trench excavated on the Uranerz property at Key Lake revealed more than 60 m of stratified sand with some gravel layers (Plate 17).

Large quantities of ice-contact stratified drift in a belt along Highway 102 between La Ronge and McLennan Lake in the Lac la Ronge area (NTS 73 P) are thought to have been deposited by meltwater flowing into Lake Agassiz through an ice-walled channel (Schreiner and Alley, 1975). This channel constituted the early stage of an interlobate area that formed as the ice thinned. A similar feature deposited ice-contact stratified drift north and south of Pelican Narrows (NTS 63 M-2).

From Map 221A (back pocket) it is evident that many eskers are flanked on either side by a broad band of outwash deposits consisting of sand and gravel; this relationship indicates that eskers developed as the ice thinned and ablated. The esker tunnels subsequently enlarged to the point of collapse, creating a channel from the subglacial floor to the surface of the ice. This channel continually widened and commonly opened headward.

Buried Valleys

Buried valleys strongly resemble the ice-walled features previously described, but differ in that they were probably initiated by preglacial drainage channels in the bedrock. Buried valleys are valleys or channels that formed in bedrock, usually prior to glaciation, and were filled with drift during glaciation (Fairbridge, 1968). A large buried valley system was outlined in the Reindeer Lake area by Alley (Schreiner et al., 1976). The valley extends north-northeast from the Whitesand Dam on the Reindeer River to the south shore of Deep Bay, then northeast for 10 km, parallelling the east shore of Reindeer Lake. It reappears on the west side of Reindeer Lake, continuing northward for a distance of about 25 km to Perry Lake. The valley width is difficult to determine but is generally greater than 2 km and may be as much as 8 km in the northern part. The surface of this feature is characterized by a large esker which is more than 1 km wide in places, exceeds 60 m in height and occurs along most of the valley's length (Plate 18). Johnston (1978) referred to this feature as a "giant esker". Large kettles, exceeding 30 m in depth, occur on the esker. Seismic work revealed that the deposits in the buried valley-esker system exceed 60 m in thickness (Schreiner et al., 1976). An excellent exposure of the valley fill can be seen at the Whitesand Dam, where a nearly vertical face reveals more than 30 m of well to poorly stratified sediments.

Recently, a similar buried valley was detected near Esker Lake, southwest of Cree Lake (V.J. Sopuck, personal communication, 1979). East of Esker Lake, the surface is regular and gently rolling, with bedrock outcrops and a thin cover of drift. West of the lake, the terrain is pitted with kettles and very hummocky. Drilling in this zone revealed over 30 m of sand and gravel in many places. The channel follows a bedrock shear zone which, being more susceptible to erosion, aided in the formation of a bedrock valley. Drainage from Glacial Cree Lake probably followed this depression and led to the deposition of sediments. Hydrologic flow patterns within the Athabasca Basin suggest that this buried valley may extend north through Cree Lake and follow the Cree River (T.J. Kewen, personal communication, 1979).

Figure 9. *Ice-walled channels in drumlinized moraine near Key Lake (NTS 74 H-4)*

Drumlins and Flutings

A drumlin is defined as a hill with an elliptical outline and streamlined form composed of glacial deposits and aligned parallel to the direction of glacial flow. Drumlin shape is not always elliptical and the composition may vary to include ice-moulded stratified drift. The nose or up-ice end is narrow and high, and slopes downwards to a broader tail in the down-ice direction. The drumlins in the study area have been described previously by Sproule (1939). They are concentrated in the northwestern, central and northeastern parts of the area, and terminate about 35 to 45 km north of the Cree Lake Moraine (Figure 7). Most are associated with the zone of thicker ground moraine described previously, which is in turn related to the sediments of the Athabasca Basin, although some lie outside this zone (e.g. around Wollaston and Phelps Lakes) but again in areas of relatively thick drift. The orientation of the drumlins varies but always parallels the ice flow direction. Drumlins in a particular area tend to have similar dimensions. They range in size from hundreds of metres in length by tens of metres in width to a maximum (near Cree Lake) of 2 km in length by 500 m in width and exceeding 50 m in height (Plate 19).

A seismic study was carried out on a drumlin at Hozempa Lake (NTS 74 J-15), the results of which are included in Appendix B. The thickness of the drift is approximately 30 m from the top of the drumlin to the bedrock surface. The seismic results also indicate that two layers exist in the drift. The upper 15 m is composed of loosely packed dry sediment which resembles sandy till. This layer exhibits stress patterns parallel to the drumlin axis, which were likely

created during the drumlin's formation. The lower 15 m, below lake level, consists of saturated material which is similar in texture to the overlying deposits but more compact. The irregular bedrock surface indicated by the seismic results may be the cause of the drumlin's formation.

An exposure in the nose of a drumlin at Key Lake (Plate 20) reveals a till thickness of about 5 m, with the upper 2 m being a different till than the lower part. These tills are shown in Plate 21 and described in the section on glacial stratigraphy. The upper unit is more or less uniform in thickness and conforms to the surface of the drumlin. The contact between the tills is sharp and truncated, indicating an erosional surface and supporting the proposal of an erosional origin. However, this one exposure was insufficient to establish whether the observed relationships are widespread; more detailed investigations would be required.

Ispatinow is a Cree word meaning 'conspicuous hill'. It was introduced by Tyrrell and Dowling (1896) to describe an extremely long, drumlin-like feature (Plate 22). Although the origin of these features is uncertain, they appear to have formed in a manner similar to drumlins, but are related to very sandy sediments and associated with the glacial lakes. *Ispatinows* occur mainly north and west of Cree Lake, along the Cree River, southeast of Black Lake, and west of Black Lake south of the Fond du Lac River. They are concentrated primarily within the basins of glacial lakes. Some *ispatinows* are more than 2 km long and less than 100 m wide, with heights ranging from less than 10 m to more than 20 m.

Flutings are another elongate, streamlined, linear landform produced by the ice. These shallow groove-like channels separated by low ridges are described by Gravenor and Meneley (1958) and Craig (1959). The few flutings found in the study area are restricted to areas of thicker drift. One occurrence, north of Brûlé Lake (NTS 74 A-12), consists of several long shallow troughs that are oriented in the direction of ice movement. In profile, they appear as smoothly rolling ridges and depressions with relief on the order of 10 m. Sand fills the depressions to a depth of 1 m and drapes up onto the mounds to a height of about 3 m.

These features were formed by an active ice mass and indicate the flow direction of the last ice movement. Drumlins and flutings were formed in the thawed-bed (abrasion) zone (Figure 10) of the glacier (Clayton and Moran, 1974) and are common regionally in the Transitional Suite (Figure 7), well back from the ice margin. Whether the drumlins are depositional features or have been eroded from pre-existing till sheets is a matter of controversy. They are probably ice-moulded forms consisting of thick accumulations of lodgement till simultaneously deposited and eroded by flowing ice.

Kettles

Kettles are basins or depressions formed in drift deposits by the melting of buried ice blocks (Flint, 1971). They can be found in many locations throughout the map area, particularly in the western half where ice-contact deposits are most abundant. Kettles are associated with outwash, eskers, kames and other ice disintegration features. Less commonly, they are found in moraine deposits. The size of these features ranges from a few metres to a few kilometres in width; some are more than 50 m deep (Plate 18). They may be single, funnel-shaped depressions or irregular, grouped and interconnected depressions. Some are filled with water. Kettles give an indication of the minimum thickness of a drift deposit.

Kames

"A kame is mound composed chiefly of sand and gravel, whose form has resulted from original deposition modified by any slumping incident to later melting of the glacial ice against or upon which the deposit accumulated" (Embleton and King, 1968,

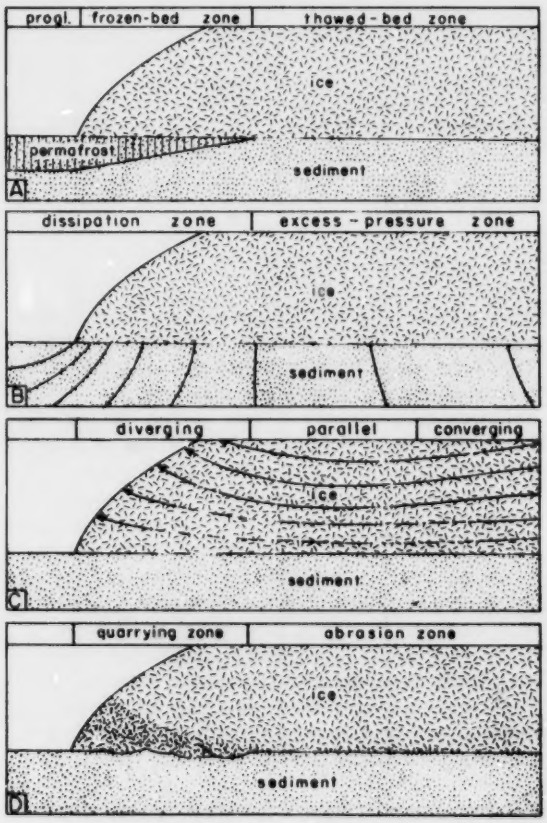


Figure 10. *Glacial process — form model (after Clayton and Moran, 1974): **A**, thermal zones; **B**, groundwater pressure zones, showing isopotential lines with the potential decreasing to the left; **C**, glacial flow zones; **D**, erosion zones*

p. 383). They range in size from small round knobs to large irregular plateaus. Kames were formed by ice-contact streams, flowing in, on, or under the ice, which dumped slightly sorted debris in cavities or as cones at the margin of a stagnant ice mass.

Kames are uncommon in northern Saskatchewan, but the few which do occur are very large. A broad, oval-shaped kame pitted with kettles lies west of Nagle Lake on the north side of the Cree Lake Moraine. Large kames or kame deltas are associated with the gap in the Cree Lake Moraine south of Jewett Lake (Map 221A, back pocket). These kame complexes commonly occur at ends of sections of the moraine. Other large kame complexes, located around Deception Lake, are up to 1 km² in area and pitted with large, deep, irregularly shaped kettles which in places indicate drift thicknesses in excess of 30 m. The kames near Jewett Lake, which are associated with the Cree Lake Moraine, were formed by meltwater flowing in a crevasse or channel parallel to the ice front and spilling into a cavity or over the ice margin as explained previously. The kames near Deception Lake were formed along a stagnant ice front. These features can be used to indicate the approximate position of an ice margin where end moraines and other terminal features are absent.

Felsenmeer

The term 'felsenmeer' or 'block field' refers to a continuous veneer of large, angular to subangular blocks of rock lying in lowlands, on hillsides or on hilltops. Block fields are commonly associated with outcrops of well-jointed bedrock.

Block fields in northern Saskatchewan range in area from less than 100 m² to several square kilometres. They are especially common along the northeastern margin of tne map area where they form the dominant ground cover in some places. Many block fields are partially masked by a thin cover of lichen and moss or other vegetation, but their rugged surface is generally apparent through this blanket (Plates 23 and 24). The blocks range from less than 20 cm to more than 2 m in diameter; the blocks of a particular field are generally similar in size. They are commonly angular and of the same rock type as the local bedrock. In places, subangular or rounded boulders of exotic lithologies are scattered among the blocks; these are probably glacial erratics. Typically, the blocks are loosely packed. Matrix material is absent, even to a depth of more than 2 m. Lichens grow on the surface of most blocks.

Freezing and thawing in a periglacial environment, which acts to break up bedrock along joints and fractures and move blocks to the surface, is generally regarded as the cause of block fields (Embleton and King, 1975).

Proglacial Landforms

Lake Agassiz

The largest and most significant glacial lake to have affected northern Saskatchewan is the northern extension of Lake Agassiz, which covered the southeastern part of the map area. The long and complex history of this large lake has been described in detail by Elson (1967). The area covered by the lake basin is roughly outlined by the extent of lacustrine silts and clays, as shown on Map 221A (back pocket). The distribution of glaciolacustrine sediments shown on this map differs from that shown by Prest et al. (1968), as they cover a large area, previously unmapped, west of the Reindeer River and north to Reindeer Lake. Lacustrine sediments are also present in the Churchill River basin, both east and west of the Reindeer River. The western extent of the lacustrine silts and clays lies just west of Lac la Ronge. The sediments of the Lake Agassiz basin partially mask the bedrock and lower drift deposits. Bare outcrop predominates in the area and bedrock structure is clearly visible on aerial photographs. The silts and clays range in thickness from less than 1 m, generally on bedrock uplands, to more than 5 m in bedrock depressions. The lacustrine sediments commonly lie directly on bedrock, but can also overlie sand or sandy till deposits. The lacustrine sequence is generally sandy at the base, becoming silty and then more clay rich toward the surface. Locally, the silts or clays are covered by a clay-rich till or, more commonly, by peat deposits.

Beaches are absent or where they do occur are only poorly developed, since bedrock outcrops and till, which together comprise most of the presumed shorelines (Langford, 1975), are not conducive to beach development. A few beaches have developed on more favourable deposits. A strandline at an elevation of about 380 m on the shore of Hunter Bay (Lac la Ronge) is developed in sand. Strandlines are cut into both the north and south sides of the Cree Lake Moraine near Pagato Lake. The south-facing beaches are up to 420 m in elevation, whereas those on the north side do not exceed 380 m. Several beaches, some of which exceed 450 m in elevation, were reported by Johnston (1978) in the Reindeer Lake area. He also described the distribution and stratigraphy of the lacustrine sediments in this area.

Because the northern beaches are not as well developed as those in the southern parts of the Lake Agassiz basin, they are of little assistance in defining elevations of former lake levels. In the Churchill River basin, numerous lacustrine sediments have been discovered up to 396 m above sea level, but few have been noted above this elevation. This indicates that the highest level of the lake was at least 396 m and possibly as much as 420 m. Langford (1977) also

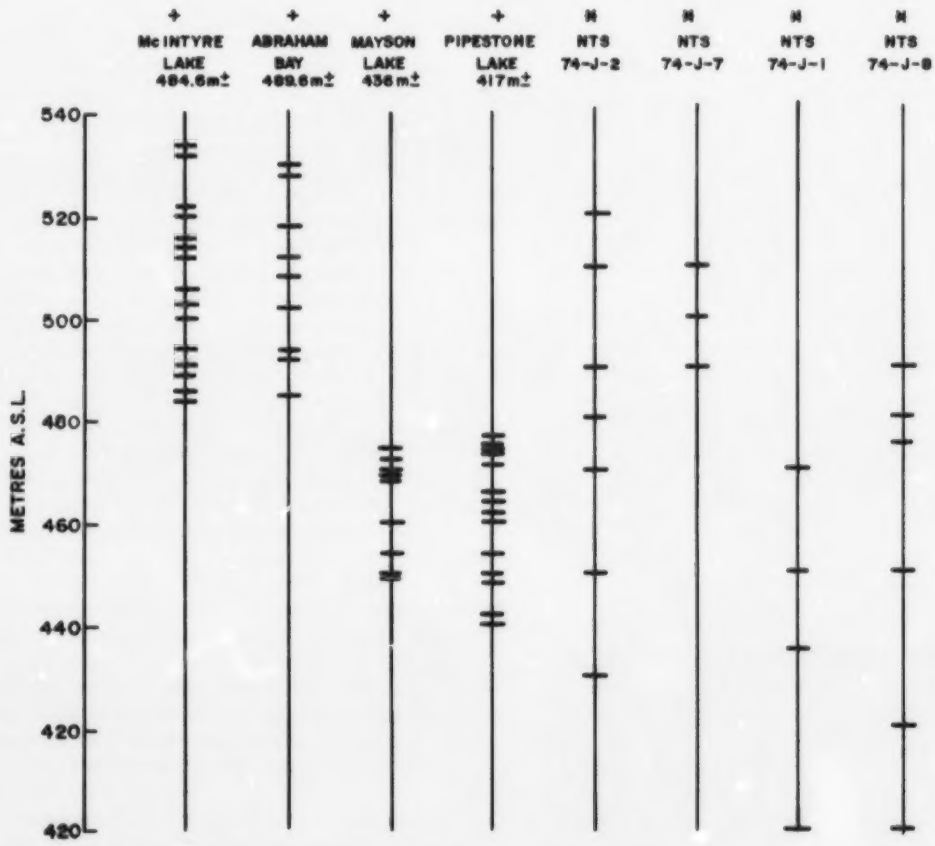
determined that the highest level of Lake Agassiz in this area was in the range 396 to 427 m.

Glacial Cree Lake

A glacial lake also occurred in the north-central part of the map area, occupying the basin which now contains Cree, Weitzel, Engeman, Mayson and Thompson Lakes and the Cree River (Figure 4). Well-developed wave-cut cliffs and terraces occur on the flanks of large drumlins bordering the present lakes (Plates 25 and 26). On the west shore of Cree Lake, the terraces on some drumlins are as high as 538 m in elevation, or approximately 53 m above present lake level. A series of lower terraces is also cut into these drumlins. Near Engeman and Mayson Lakes, terraces in drumlins occur at a maximum elevation of 470 m, but lower terraces can also be noted. Strandlines can be seen on aerial photographs. These wave-cut benches are not continuous, but can still be traced for several kilometres.

The lake also inundated the lowlands extending north from Cree Lake along the Cree River. Numerous strandlines are noted west of Thompson Lake, the highest of which, located east of Rosenlett Lake (NTS 74 J-2) and around Rumpell Lake and Bruce Lake (NTS 74 J-7), are 510 to 520 m in elevation. Particularly well-developed strandlines at elevations of 480, 450, 420 and 400 m occur as far east as the Cree River (Figure 11). Spillways, cut into sediments east and west of Pasfield Lake (NTS 74 I-6), correspond to the three lower levels of Glacial Cree Lake. A strandline at about 460 m is evident around the shorelines of Waterbury and Unknown Lakes (NTS 74 I-SE), indicating that the glacial lake extended this far east (Map 221A, back pocket).

Aerial photographs reveal the slightly smoother topography of the lake basin compared to the surrounding terrain. Deep gullies are cut into the fine sediments along the Cree River. However, drumlins, particularly those which form the many islands in



Strandlines defined by beaches, terraces and spillways

+ Elevations of strandlines hand levelled from surface of lake; estimated accuracy ± 3m (lake elevations from 1:50,000 topo. maps)

* Elevations of strandlines taken from 1:50,000 topographic maps with 10m contour interval; estimated accuracy ± 5m

Figure 11. Strandlines of Glacial Cree Lake

Cree Lake, dominate the landscape. *Ispatinows* appear to be concentrated within the lake basin but do occur outside its margins. Hummocky fluvial deposits of sand and gravel, characterized by eskers, kames and kettles, are scattered throughout the basin. Lacustrine silts and clays are nearly absent because the drift was derived from the sandstone, which contributes very little fine material. Sand is the dominant sediment deposited in the glacial lake, as indicated by the abundant sand plains, beaches, spits and bars. Clay and silt have reportedly been encountered in the lake basin in diamond-drill holes. These sediments appear to be restricted to the deeper parts of the lake.

Glacial Cree Lake was dammed by ice to the north (Figure 31) and the lake initially drained through the Mudjatik River into the Churchill River. The drainage threshold of Glacial Cree Lake was at an elevation of about 490 m. The fact that the beaches are about 50 m higher than the threshold in the drainage outlet suggests that differential isostatic rebound took place as the ice melted. As the ice retreated, the glacial lake expanded northward. Eventually, successive drainage outlets were opened to the west and the lake drained in stages, resulting in the development of the more significant strandlines (Figure 32).

Glacial Lake Athabasca

The glacial lake which occupied a large area around present-day Lake Athabasca and extending along the Fond du Lac River to Black Lake is the eastern extension of Glacial Lake McConnell (Craig, 1965). The areal extent and history of this large lake, which is referred to under a variety of names, is described by Tyrrell and Dowling (1896), Cameron (1922), Taylor (1960) and Craig (1965). The portion of the lake which surrounded the present Lake Athabasca is here referred to as Glacial Lake Athabasca. Its areal extent is roughly outlined by the 305 m contour line and corresponds closely to the distribution of lake sediments, as shown by Prest et al. (1968). The extent and history of this lake are shown by the maps outlining the deglaciation phases in northern Saskatchewn (Figures 31 to 34).

Strandlines of Glacial Lake Athabasca are found at many locations within the map area, on both the north and south sides of the present-day lake and extending along the Fond du Lac River to Black Lake (Figure 12). The highest strandlines, at an elevation of about 305 m, are marked by terraces cut into drift in highland areas south of Pederson Lake and Royal Lake (NTS 74 N-2). Terraces and beaches at Fish Hook Bay (NTS 74 N-8), Riou Lake (NTS 74 O-1) and along the Black Lake road, and fluvial sand and gravel deltas in the Uranium City area also indicate a lake level at about 305 m (Plates 27 and 28). These features indicate that the highest strandlines are more or less consistent in elevation over the entire extent of the lake.

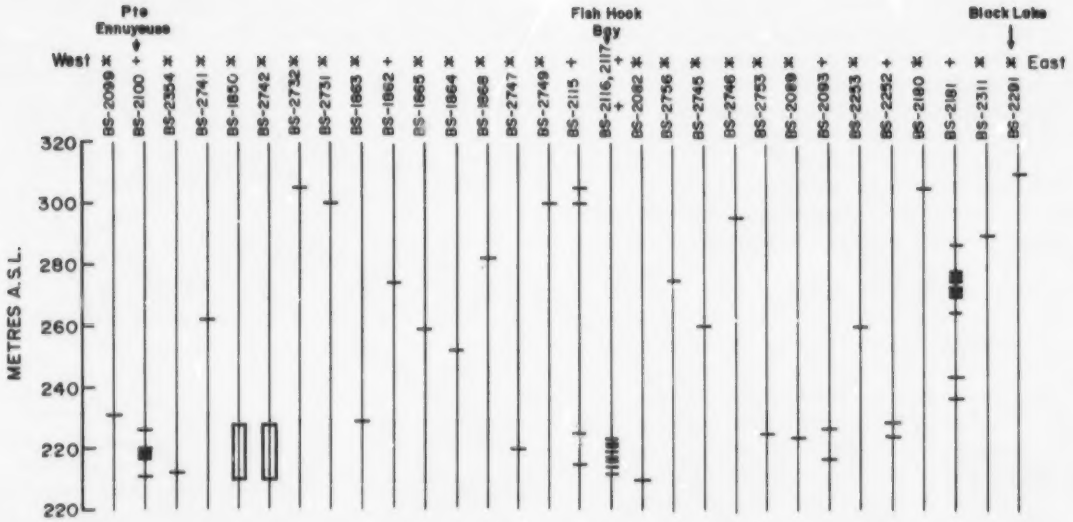
Other significant strandlines are developed at elevations of 290, 260 and 230 m. These levels may correspond to hinge lines associated with isostatic rebound. Between these fairly well defined levels, and especially below 230 m, are other less obvious strandlines (Plate 27). These are developed at nearly regular intervals of about 1 m. They probably correspond to the raising of the land surface by isostatic readjustment.

Although sand is the dominant sediment within the basin of Glacial Lake Athabasca, a 29 m thickness of silt and clay was encountered in an augerhole drilled in the present lake just north of Ennuyeuse Creek and about 1.5 km from shore (BS-2353). These sediments were pinkish grey in colour, rubbery in texture and devoid of organic material, suggesting deposition in a glaciolacustrine environment. More than 15 m of glaciolacustrine sand was encountered in each of two other augerholes (BS-2355, -2356) drilled at elevations of about 260 and 230 m. Augerholes drilled successively further to the south at elevations above 290 m revealed glaciofluvial sand and gravel. Silt was found at several locations in the Uranium City area. At one site (BS-1890), till was overlain by about 1 m of pinkish-white silt. An exposure of white silt with a blocky structure (BS-2300) was noted along the Fond du Lac River just west of Stony Rapids (Plate 29). A similar exposure was observed from the air at the north end of Stony Lake. At one locality on the Black Lake road (BS-2318), sand deposits are overlain by about 1 m of sandy silt, which is in turn overlain by about 1 m of clayey silt. Sand forms level plains which surround Black Lake at elevations below 305 m.

Glacial Wollaston Lake

The Wollaston Lake basin and surrounding area was also occupied by a glacial lake. Cobble beaches found at an elevation of about 420 m, just south of Pow Bay on the west shore of Wollaston Lake (BS-2621), mark the highest strandline detected. Stratified sands occur along the Wollaston Lake road (BS-2549), also at an elevation of about 420 m. Commonly, the shoreline was bedrock outcrop. Sediments range from fluvial sands and gravels to sandy till; glaciolacustrine sediments are rare in this basin. No evidence of a former glacial lake was found around the northern part of Wollaston Lake.

Drainage to the north through the Cochrane and Fond du Lac Rivers was blocked by ice. Water was ponded in the basin and drained southeast through the Swan Spillway to Reindeer Lake. When the ice retreated from the area around Hatchet Lake, the glacial lake drained by way of the Fond du Lac River (Figures 33 and 34).



Strand lines defined by beaches, terraces and deltas along Lake Athabasca, Fond du Lac River and Black Lake (See open file for site locations and details)

+ Elevations of strandlines hand levelled from surface of lake; estimated accuracy ± 3 m (lake elevations from 1:50,000 topo. maps)

* Elevations of strandlines taken from 1:50,000 topographic maps with 10 m contour interval; estimated accuracy ± 5 m

Strandlines at sites BS-1850 and BS-2742 were too close in elevation to be represented separately

Figure 12. Strandlines of Glacial Lake Athabasca

Glacial Reindeer Lake

The Reindeer Lake basin was partially occupied by a glacial lake. Bedrock outcrop dominated the shoreline. Lacustrine sands, silts and some clays, generally less than 3 m in thickness, are concentrated in low-lying areas and are generally covered by muskeg. Raised beaches are commonly developed in sand; a few boulder beaches also occur. The beaches and the distribution of lacustrine sediments indicate that water levels did not exceed 12 m above the present lake level of 336 m. Reindeer Lake was occupied by Lake Agassiz when Lake Agassiz was in one of its lower phases. The raised beaches may be due to isostatic rebound, or water might have ponded in the basin when drainage to the south and west was restricted. The relationship of Glacial Reindeer Lake to Lake Agassiz is illustrated in Figures 33 and 34.

No indications of a lake level higher than the present level of Reindeer Lake were detected north of Latitude 57°N. The shore deposits are fluvial sand and gravel and sandy glacial till. Bedrock still dominates the shoreline.

Meltwater Channels

Several rivers flow from the central part of the map area south to the Churchill River, the largest being the Mudjatik, Haultain, Foster and Paull Rivers (Figure 4). All functioned as meltwater channels. The discharge of these channels was high, as indicated by the wide sand plains bordering the Mudjatik and Haultain Rivers, especially south of the Cree Lake Moraine. The Foster and Paull Rivers, however, do not have such wide sand plains since their channels are confined to narrow bedrock valleys. The present-day river channels meander on the sandy valley fill (Plate 30).

Meltwater flowed south through these channels to the Churchill River. Sediment carried from the ice was largely deposited in the meltwater channels or as deltas where the channels entered the chain of lakes that comprise the Churchill River system. For instance, a delta was formed in Dreger Lake where the Haultain River enters the Churchill, while a smaller delta at Dipper Lake trapped much of the sediment carried by the Mudjatik River. The Churchill River itself does not contain many fluvial deposits.

The Clearwater River and its tributaries also acted as a major meltwater channel. At present, it flows in a wide, deeply incised valley which cuts through Cretaceous and Devonian bedrock to expose the Precambrian basement (Plate 31). The river meanders in the valley bottom, eroding the sand deposits that make up the floor of the valley. Sand bars are evident in many parts of the river. Evidence of deposition on slip-off slopes, in the form of meander scrolls, and of erosion on the cutbank can be seen in numerous places along the river (Plate 32).

The Reindeer River, which connects Reindeer Lake to the Churchill River, did not carry much meltwater. A short southeasterly-trending outwash channel connects Steephill Lake to the Reindeer River and bypasses the bend in the river east of Steephill Rapids.

The remaining large rivers in the area flow northwards. Ice blocked these rivers temporarily, thus preventing them from carrying much meltwater. Their main features were formed when they later acted as spillways draining the glacial lakes.

A number of rivers flow southwards into Lake Athabasca, the Fond du Lac River or Black Lake. Many of these acted as meltwater channels. The banks are commonly bedrock, so there was little erosion. Deposition in the meltwater channels was uncommon except where they entered Glacial Lake Athabasca. The Grease River, flowing southwest to the Fond du Lac River, is a good example. The upper part of the river is bedrock controlled, while broad sand plains fill the lower part to an elevation of about 300 m. Terraces, which probably correspond to the lowering of water levels in the glacial lake, are cut into the sand plains. Similarly, stratified sands and gravels occur at certain levels in a number of bedrock valleys in the Uranium City area, but are especially common at about 305 m. Meltwater draining from the ice deposited sand and gravel in deltas where it entered the glacial lake. The elevations of these deltas correspond to the various lake levels, particularly the maximum level of 305 m.

Spillways

A spillway is a channel through which a glacial lake drained. Many of the meltwater channels mentioned previously acted as temporary spillways. Several spillways in the western half of the area cut through the Cree Lake Moraine and carried water, previously impounded behind the moraine, to the Clearwater River system. One of the most outstanding examples is a spillway south of Preston Lake which cut down through more than 25 m of drift and is up to 400 m wide in some places. An augerhole (BS-1746) on the southern flank of the valley revealed more than 35 m of sand and gravel.

Water impounded behind the Cree Lake Moraine eventually breached it south of Reindeer Lake to form several well-developed spillways which extend southwards from Harriott and Kamatsi Lakes. A short spillway extends north from Kamatsi Lake to Wapus Lake along a straight, narrow, structurally-controlled drainage way. They all carried water south to the Churchill River. Other spillways throughout the area flowed southward, the most significant being the Mudjatik Channel which drained Glacial Cree Lake and the Clearwater Channel which drained Glacial Meadow Lake (Christiansen, 1979, Figure 17).

The remaining major spillways flowed northward. The William, MacFarlane, Snare, Otherside and Cree Rivers acted as spillways, draining Glacial Cree Lake into Glacial Lake Athabasca. The Fond du Lac River drained Glacial Wollaston Lake. Each of the spillways has a wide drainage course which often cuts through drumlins and other features to form steep banks. The present rivers meander within the old channels, displaying such typical characteristics as braiding and meander scars. Outwash plains occur where the channels enter small lakes or level areas. The Snare and MacFarlane Rivers are the best examples of such spillways (Plate 33). Large deltas were formed where many of these spillways entered Glacial Lake Athabasca. Subsequently, the rivers cut terraces in these deposits corresponding to the lowering of the glacial lake level.

Outwash Plains

Much of the finer outwash (e.g. stratified sands) is restricted to meltwater channels. Large outwash fans or aprons occur south of the Cree Lake Moraine, especially in the western half of the area (Map 221A, back pocket). To the north of the moraine, the outwash material is generally coarser, ranging from stratified sand to sand and gravel. The outwash occurs as a discontinuous veneer of sand and gravel overlying the till or bedrock. Outwash is also found in front of the smaller end moraines in the area. Much of the level sand plain around Archibald Lake may be outwash, formed when the ice stood at the moraine north of Ens Lake (NTS 74 N-1). In the eastern half of the area, outwash was commonly deposited in ice-walled channels and often forms eskers. The topography of the outwash plains is undulating to rolling and in places hummocky; kettles are a characteristic feature. The thickness of most outwash is between 5 and 10 m (BS-1237).

A broad, nearly flat outwash plain southwest of La Ronge is composed of medium to fine sands. Coarse to fine sands and gravels occur sporadically along Highways 2 and 102 from La Ronge to about 50 km north of Missinipe (Figure 1). Thick stratified sediments deposited within an ice-walled channel near Key Lake have already been described (Plate 17). In the western half of the area, the outwash can be identified from aerial photographs by its rolling to hummocky surface pitted with kettles (Plate 34). The abundance of outwash deposits can be attributed to large quantities of sandy englacial debris, picked up by the ice when it overrode the Athabasca Basin, and to the large amounts of meltwater which led to the formation of these sediments.

Postglacial Landforms

Beaches

Many lakes, both large and small, have broad well-developed sand beaches, recognizable on airphotos, along parts of their shorelines. The lakes with beaches are more commonly found in areas that have sandy drift, especially in the western half of the study area where the drift is thicker and very sandy. Usually, outwash sands permit the best beach development, although eskers and other fluvial deposits are commonly reworked to form beaches. Locally, sandy till may contribute sediment to a beach.

Along the south shore of Lake Athabasca, very well developed beaches, berms, point bars, spits and other shallow water features have formed since the glacial lake waters receded. The primary sources of sediment seem to be the William and MacFarlane Rivers, although other material is added to the lake by small streams and some sediment is carried along the shore from the Athabasca River delta at the southwestern end of the lake. The sediment is carried and worked by longshore currents and wind and wave action, during both normal and storm periods, to form the shoreline features. Successive beach ridges have been built at William Point (Plate 35), Beaver Point and the mouth of the MacFarlane River.

Particularly well developed beaches, as well as point bars, spits and other features, occur around Costigan Lake (Plates 36 and 37) in the central part of the map area (NTS 74 A-13). All these features were formed postglacially by the reworking of sandy till and fluvial deposits. The size of these and other beaches is believed to be too large for them to have developed through modern wave action, even under storm conditions. Some of the larger ones may have formed shortly after retreat of the ice, when water had reached near-normal levels. Strong winds, suggested by the presence of abundant sand dunes, could have been responsible for the strong wave action necessary for development of such large beaches.

Deltas

Large well-developed deltas occur where the William and MacFarlane Rivers enter Lake Athabasca. In the case of both rivers, but particularly the William River (Plate 35), sand is supplied by sand dunes to the west, causing the river to be braided and meandering in its lower reaches. When the sand-laden water reaches the lake, a delta is built by the distributaries of the main river.

Other deltas are currently being built along this shoreline by smaller streams. Deltas in most other lakes throughout the map area were built by meltwater streams carrying sediment from the ice to a glacial lake.

Lake Ramparts

Another feature found along some shorelines in the area are lake ramparts. These irregular, narrow, sharp-crested ridges, generally less than 1 m in height (Plate 38), are composed of till, sand and gravel, pebbles, cobbles or combinations of these materials; boulders may be lying on the surface. Generally more than one ridge parallels the shore. Lake ramparts were formed either by expansion of lake ice or by rafting of ice floes during spring break-up. In shallower portions of the lake near the shoreline, the moving ice pushes ahead of it material scraped from the bottom; when the ice melts, this material remains in the form of mounds or ridges.

Muskegs

Muskegs, and their relation to the northern environment in Canada, are described by Radforth and Brawner (1977). The classification of peat landforms in Manitoba, including various types of bogs, fens and swamps, by Tarnocai (1974) applies equally well to the peat landforms in northern Saskatchewan. Wetlands or, as they are more commonly known, muskegs are significant landforms in the map area, covering about 10 percent of the land surface (Map 221A, back pocket). Along the southern boundary of the Shield in Saskatchewan, muskegs are exceptionally extensive, commonly occupying hundreds of square kilometres (Plate 39). In fact, they can be the dominant landform in a given area. On the Shield, muskegs tend to be smaller in size, ranging from tens of square kilometres to less than one square kilometre. In the area of thinner drift covering crystalline basement rocks, wetlands may occur in a perched position, occupying depressions in the bedrock (Plate 40). Only in periods of high runoff does a perched muskeg overflow its margins and activate intermittent streams in the bedrock valleys. The remainder of the muskegs conform to topographic features and therefore have very irregular shapes, similar to the lakes. Long narrow wetlands fill many of the valleys.

To the west, in areas of thicker drift and particularly overlying the Athabasca Basin, the wetlands occupy low areas between drumlins, eskers and other topographically higher features (Plate 41). Perched bogs are rare due to the high permeability of the drift and the lack of depressions at higher elevations. Some muskegs may lie directly on bedrock, especially on the flat-lying Athabasca Group. Several muskegs were augered and sampled for radiocarbon analysis to determine the minimal age of deglaciation (Table 2).

Permafrost

Northern Saskatchewan lies within the zone of discontinuous permafrost (Brown, 1967). The

frequency of permafrost occurrence increases from southwest to northeast across the map area, its distribution being related to certain aspects of topography, drainage, soils, vegetation and other terrain factors (Brown, 1965, Figure 25). Features indicative of permafrost can be seen from the air as well as on the ground, especially in the northeastern half of the area. Muskegs with 'drunken forests' (leaning and fallen trees) provide evidence of permafrost at depth. *Palsen* (peat mounds with ice cores) were recognized from the air in low-lying areas (Plate 42).

A number of *palsen* were examined along the Wollaston Lake road (Highway 105) at the southwest end of Hidden Bay. These mounds are about 10 to 20 m wide and 3 to 4 m in height, and are surrounded by wet muskeg. They are composed of dark brown silt covered with a layer of peat which commonly exceeds 1 m in thickness. Peat was spalling off along the edges of the mounds, indicating that thawing was taking place. The mounds were probed to a depth of more than 2 m, but no frozen material was encountered by the probe or in any of the exposures. Frozen sediment containing ice crystals was encountered at a depth of 1 m in a depression between two mounds.

An exposure northeast of Uranium City (BS-1891) revealed about 1 m of peat which was frozen at the base. Subsequent checks during the summers of 1978 and 1979 indicated that the frozen peat was thawing.

A *palsa* located west of Highway 102 near the junction of Highway 105 (DA-631) consists of a mound of peat rising about 2 to 3 m above the surrounding water level. The mound is composed of about 2 m of peat covering an ice core (Plates 43 and 44); leaning trees, sphagnum moss and other muskeg vegetation cover the surface. A sample of the peat, taken just above the frozen layer, gave a radiocarbon date of 6420±115 years B.P.

A small fossil pingo was found near Yakow Lake (NTS 74 N-1). This eroded mound or bulge of sediments (Plate 45) consists of a grey silty layer about 0.5 m thick which has been tilted to a vertical position. The upturned silt bed forms a circular feature about 3 m in diameter at the ground surface. Sandy fluvial sediments with graded bedding form the core of the feature. The water table lies about 1.5 m below the surface, but no permafrost was detected to a depth of 2 m. Eolian beds on the flanks of the structure are also contorted and suggest that eolian activity occurred while periglacial conditions still existed.

Small mounds or hummocks, commonly less than 1 m in diameter, were encountered in clay deposits. Similar features were noted by F.F. Langford in the Churchill River area, as reported by Kupsch (1975). Excavations into these hummocks did not reveal any ice, suggesting that the mounds may be remnants of degraded permafrost, a conclusion also reached by Kupsch (1975).

Permafrost was encountered in lake sediments north of the Churchill River and east of the Reindeer River (Sopuck et al., 1977) in the Pelican Narrows area (NTS 63 M). Frozen ground was encountered in lake silts directly below a thin cover of moss (Plate 46) near Maribelli Lake in the Upper Foster Lake area (NTS 74 A-1). Because this well-shaded site was sampled on June 15 (BS-555), the frozen ground may have been seasonal frost that persisted into late spring or early summer. Permafrost is not a common occurrence in the very sandy, usually well-drained deposits in the western part of the map area.

Permafrost is scattered throughout the lacustrine sediments but is mainly confined to low-lying areas of bog where the layers of peat, moss and other vegetation insulate the frozen ground and prevent thawing.

Eolian Features

Sand dunes are limited to the western half of the area, as indicated on Map 221A (back pocket). Concentrations of active sand occur south of Lake Athabasca and Black Lake. Inactive dunes are widespread but are particularly abundant north and south of the Cree Lake Moraine.

The more common form of inactive dune has a V shape (Plate 47), with the apex pointing to the northwest (the downwind direction at the time of formation), and is similar to parabolic dunes; this is the Cree Lake type of David (1977a, 1977b). A second form has a circular shape with very ragged or zig-zag edges (Plate 48); this is the Lake Athabasca embroidery pattern of David (1977a). Most of these dunes are anchored by a covering of vegetation. Both types are described in detail by David (1981a).

A number of different dune forms have been described by David (1977a, 1977b) in the active dune areas south of Lake Athabasca (Plate 49). They have been formed mainly by northwesterly winds from the sandy sediments of Glacial Lake Athabasca. These sediments were deposited in deltas where the major rivers (e.g. the William River) entered the glacial lake. As the lake receded, the deposits dried out and were picked up by the wind to form the large active sand dune areas. The Athabasca Sand Dunes have been investigated by David (1981b).

Etched boulders, which have been blasted by sand-laden winds, are another indicator of eolian activity. The boulders, particularly abundant on the surface of

moraines, are commonly Athabasca Group sandstone (Plates 50 and 51) and are scattered throughout most of the western half of the area. The etching consists of shallow pits and grooves cut into the boulders along presumably less resistant beds or other planes of weakness. Generally, the etched surface is smoothly polished compared to the downwind faces. Resistant grains, commonly large quartz crystals, stand out above the eroded surface. Sandblast features generally occur on the southeast-facing sides of boulders, while less pronounced evidence of wind action may be found on surfaces with other orientations. The distribution of etched boulders, the degree of wind abrasion, and the fact that southeast-facing surfaces are most affected indicate that the sand which etched the boulders was transported by strong consistent winds from the southeast.

In the Athabasca Sand Dunes, sandblast features are found on both the southeast- and northwest-facing sides of some boulders and cobbles (Plate 52). These two wind directions coincide with those indicated by the orientation of major dune forms in the area.

Surficial Sediments

Glacial Sediments

Very Sandy Till

Very sandy till, derived primarily from sediments of the Athabasca Group, is the second most abundant glacial sediment. This till generally overlies the sandstone bedrock but also occurs southwest of the sandstone, where it is underlain by basement rocks and in some places Phanerozoic rocks. This sandstone-derived till is found throughout much of the western half of the study area as the main component of ground and end moraine (Map 221A, back pocket). An augerhole (BS-1742) located west of Wasekamio Lake (NTS 74 C-10) revealed more than 35 m of very sandy till.

This till commonly contains subangular to subrounded boulders of varying sizes (Plates 53 and 54); pebbles and cobbles are also subangular to subrounded. The light grey, grey or pinkish colour of this till in augerholes is due to the colour of the parent sandstone, which varies from near-white to pink and dark purple depending on the hematite content. The colour in surface samples, white to very pale brown and brown, is due mainly to oxidation.

This very sandy till is less variable in composition than the sandy till derived from Precambrian basement rocks. The sand content varies from less than 60 percent to greater than 95 percent, but is generally greater than 80 percent (A1, Table 1). Silt, which dominates the fine fraction (<0.05 mm), commonly ranges from less than 20 percent to absent. Figure 13 shows the grain-size distribution in a typical sample of the very sandy till.

The till matrix is composed of mineral grains of varying lithologies, comminuted from rock fragments which were eroded from the bedrock. Grain size depends on the hardness, cleavage and other characteristics of the constituent minerals and on the severity of grinding. Assuming that the grinding process is a constant, certain grain sizes predominate, depending on the kinds of minerals present. The sandy modes reflect the nature of the bedrock source but also suggest a relatively short transport distance. Longer transport by ice results in a finer till matrix and a shift in the grain-size distribution toward the finer fractions.

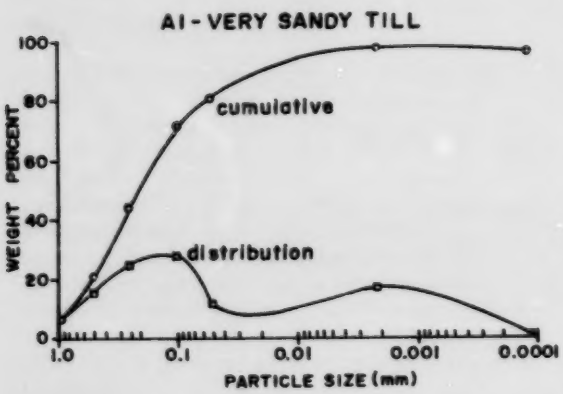


Figure 13. Mean grain-size graphs for very sandy till overlying the Athabasca Group in the northwestern part of the map area (from Table 1)

The sand fraction of the very sandy till, when subdivided into components, reveals only a single mode (Figure 13). A second mode may exist in the material coarser than sand. Another mode occurs in the fine size range (<0.05 mm), but this fraction is usually a relatively small part of the total sample. The existence of only one mode in the sand fraction, which normally occurs at the fine sand size, is due to the relatively homogeneous mineralogy and grain size of the sandstone source material in comparison to the Precambrian basement rocks.

Sandy Till

Sandy till, the most common glacial sediment in the map area, occurs in various types of moraine and its component landforms (e.g. drumlins). It is derived by glacial erosion of local bedrock and pre-existing glacial deposits.

Sandy till derived from basement rocks contains an abundance of large, angular, igneous and metamorphic boulders which commonly dominate the deposit (Plate 55). Pebbles and cobbles are angular to subangular. The brown upper part of the till is oxidized, whereas the deeper part, grey in colour, is unoxidized. The depth to which oxidation has affected the till varies, but in places exceeds 5 m.

The grain size of the sandy till varies considerably, a common characteristic of till deposits (Goldthwait, 1971). Sand, the dominant component of the till matrix, ranges from 50 to 90 percent, whereas silt ranges from less than 5 to more than 40 percent and clay from less than 10 percent to negligible amounts (B2, B3, B5, Table 1). Figure 14 shows the grain-size distribution in a typical sample of sandy till. The grain-size distribution in the sand fraction is commonly multimodal, with high contents of coarse and fine sand. Another mode exists in the silt range (Figure 14). The mineralogy of the fine fraction of the sandy till matrix, as indicated by x-ray diffraction (Figure 15A), reflects the bedrock source. Quartz, feldspar, amphibole and other minerals derived from igneous and metamorphic rocks dominate the graph. Chlorite, kaolinite, illite and possibly some micaceous minerals are also present. Some are derived directly from the bedrock, while others are alteration products of minerals such as feldspars.

Table 1. Grain Size Analyses for Surficial Sediment Samples from Five Zones Within the Map Area

Set	Texture	A Very Sandy Till			B Sandy Till			C Silty Till			D Clayey Till			Sand		
		Mean (wt. %)	σ (wt. %)	No. of Samples	Mean (wt. %)	σ (wt. %)	No. of Samples	Mean (wt. %)	σ (wt. %)	No. of Samples	Mean (wt. %)	σ (wt. %)	No. of Samples	Mean (wt. %)		
1	SAND	84	8	183				48	6	9	57	0	1	95		
	SVC	7	4	181				4	3	9	3	0	1	6		
	SC	15	5	181				8	2	9	10	0	1	23		
	SM	22	7	181		NA		10	3	9	15	0	1	31		
	SF	29	7	181				13	5	9	20	0	1	29		
	SVF	11	5	181				13	4	9	9	0	1	6		
	SILT	15	7	183				48	4	9	33	0	1	5		
	CLAY	1	1	183				3	2	9	10	0	1	1		
2	SAND				71	10	141	45	9	23	39	17	75	82		
	SVC				12	7	141	6	4	23	7	5	73	13		
	SC				13	4	141	7	2	23	8	4	73	15		
	SM		NA		11	4	141	6	2	23	6	3	73	13		
	SF				11	6	141	12	4	23	10	5	73	23		
	SVF				15	5	141	14	5	23	8	3	73	18		
	SILT				25	8	141	49	9	23	38	12	75	15		
	CLAY				4	2	141	6	2	23	23	12	75	3		
3	SAND				73	9	284	48	8	74	37	21	16	87		
	SVC				13	7	283	6	3	74	6	5	16	18		
	SC				14	6	283	8	3	74	8	6	16	19		
	SM		NA		12	4	283	6	2	74	6	4	16	15		
	SF				20	5	283	13	4	74	9	5	16	23		
	SVF				15	5	283	15	6	74	9	5	16	14		
	SILT				25	9	284	49	7	74	48	18	16	11		
	CLAY				2	2	284	3	2	74	16	8	16	1		
4	SAND	83	9	112				43	13	5	71	7	4	96		
	SVC	9	7	111				3	2	5	7	4	4	11		
	SC	15	6	111				6	2	5	14	4	4	26		
	SM	20	5	111		NA		9	4	5	18	5	4	31		
	SF	27	9	111				11	6	5	21	10	4	23		
	SVF	11	5	111				14	4	5	11	3	4	6		
	SILT	15	9	112				54	11	5	18	7	4	3		
	CLAY	2	2	112				3	3	5	12	2	4	1		
5	SAND				73	10	245	46	9	93	62	17	7	93		
	SVC				13	7	244	7	3	92	17	14	7	21		
	SC				14	5	244	8	3	92	13	3	7	25		
	SM		NA		11	4	244	6	2	92	8	3	7	17		
	SF				20	6	244	12	4	92	14	8	7	22		
	SVF				14	5	244	13	5	92	9	5	7	8		
	SILT				25	9	245	50	9	93	25	19	7	5		
	CLAY				2	2	245	4	2	93	13	3	7	1		

Legend:

- wt. % = Weight Percent
- σ = Standard Deviation
- SAND = Total Sand (2.0 - 0.05 mm)
- SVC = Sand Very Coarse (2.0 - 1.0 mm)
- SC = Sand Coarse (1.0 - 0.5 mm)
- SM = Sand Medium (0.5 to 0.25 mm)
- SF = Sand Fine (0.25 - 0.10 mm)
- SVF = Sand Very Fine (0.10 - 0.05 mm)
- SILT = (0.05 - 0.002 mm)
- CLAY = (<0.002 mm)
- NA = Not Available

Set 1: Composed of samples collected over the Athabasca Group in the northwestern part of the study area (NTS 74 F-9, -10, -15, -16; 74 G-6 to -16; 74 H-5, -11 to -15;

Set 2: Composed of samples collected over Precambrian basement and within the Lake Agassiz basin in the southeastern part of the study area (NTS 63 L-1 to -16; 63

Set 3: Composed of samples collected over Precambrian basement in the southeastern part of the study area (NTS 64 D-5 to -16; 64 E-1 to -16; 74 A-1 to -16; 74 H- 1, -

Set 4: Composed of samples collected over Precambrian basement in the southwestern part of the study area (NTS 73 O-9, -15, -16; 74 B-1 to -16; 74 C-8, -9, -10, -15,

Set 5: Composed of samples collected over Precambrian basement in the northern and northeastern parts of the study area (NTS 64 L-1, -2, -7, -10, -15, -16; 64 M-1 to

E Sand & Gravel			F Silt			G Clay			H Colluvium			I Eolian Sand		
Mean (wt. %)	σ (wt. %)	No. of Samples	Mean (wt. %)	σ (wt. %)	No. of Samples	Mean (wt. %)	σ (wt. %)	No. of Samples	Mean (wt. %)	σ (wt. %)	No. of Samples	Mean (wt. %)	σ (wt. %)	No. of Samples
95	9	261	29	13	14									
6	11	260	0	0	14									
23	18	260	2	2	14									
31	15	260	3	3	14		NA			NA			NA	
29	20	260	6	6	14									
6	10	260	19	12	14									
5	9	261	65	11	14									
1	1	261	6	7	14									
82	17	110	15	14	108	5	5	112	23	12	5			
13	19	102	2	5	30	1	1	8	5	3	4			
15	15	102	3	4	30	2	2	8	4	1	4			
13	12	102	3	2	30	2	1	8	3	1	4		NA	
23	15	102	8	7	30	3	2	8	7	1	4			
18	16	102	15	10	30	3	2	8	9	3	4			
15	15	110	62	13	108	27	11	112	43	21	5			
3	4	110	23	14	108	68	13	112	34	30	5			
87	14	195	23	14	51	9	11	2	19	0	1			
18	21	188	1	1	34	2	0	1	4	0	1			
19	16	188	2	2	34	3	0	1	5	0	1			
15	12	188	2	2	34	3	0	1	3	0	1		NA	
23	18	188	6	4	34	5	0	1	3	0	1			
14	16	188	18	10	34	5	0	1	3	0	1			
11	13	195	64	10	51	25	4	2	63	0	1			
1	3	195	12	13	51	67	15	2	18	0	1			
96	6	137	34	10	10							98	2	4
11	14	135	1	1	8							0	1	4
26	17	135	2	1	8							13	9	4
31	14	135	3	1	8							48	11	4
23	19	135	8	5	8		NA			NA		32	18	4
6	9	135	20	9	8							5	3	4
3	6	137	61	9	10							1	2	4
1	1	137	5	8	10							1	1	4
93	10	119	28	14	22									
21	23	119	1	1	19									
25	17	119	2	2	19									
17	13	119	2	2	19		NA			NA			NA	
22	20	119	8	5	19									
8	11	119	18	9	19									
5	8	119	64	10	22									
1	4	119	8	9	22									

I-5, -11 to -15; 74 I-1 to -16; 74 J-1 to -16; 74 K-1, -2, -7 to -10, -15, -16; 74 N-1, -2; 74 O-1 to -4)

L-1 to -16; 63 M-1 to -16; 64 D-1 to -4; 73 P-1 to -4, -7 to -10, -16)

-16; 74 H-1, -2, -7, -8)

), -9, -10, -15, -16; 74 F-1, -2, -7, -8; 74 G-1 to -4)

-16; 64 M-1 to -16; 74 N-5 to -16; 74 O-5 to -16; 74 P-5 to -16)

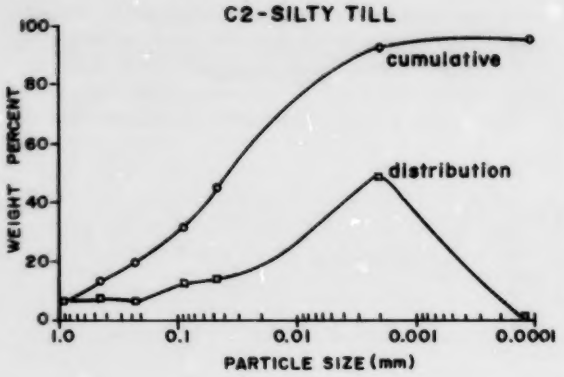


Figure 16. Mean grain-size graphs for silty till overlying Precambrian basement rocks within the Lake Agassiz basin in the southeastern part of the map area (from Table 1)

Clay". The high clay content of the till and the presence of montmorillonite both suggest that the till was derived, at least in part, from the lacustrine sediments of the lake basin.

Proglacial Sediments

Fluvial Sand and Gravel

Sand and gravel deposits are most abundant in the northwestern two-thirds of the map area, northwest of Highways 102 and 105 and south of Lake Athabasca, the Fond du Lac River and Black Lake. The Wollaston Lake (NTS 64 L) and Phelps Lake (NTS 64 M) areas also contain significant sand and gravel deposits. These coarse sediments are the primary constituent of glaciofluvial landforms such as eskers, kames, kettles, crevasse fillings, outwash plains and ice-walled channels. The coarsest material generally comprises cobbles and pebbles, most of which are subangular to subrounded, indicating relatively short fluvial transport. Sorting is commonly moderate to poor. At depth, the sand and gravel is commonly grey to grey-brown. At surface, and extending to depths in excess of 10 m, oxidation has altered the colour of these permeable sediments to yellow or yellowish brown. The base of the oxidized zone is interpreted to represent the lowest postglacial water table during the last deglaciation.

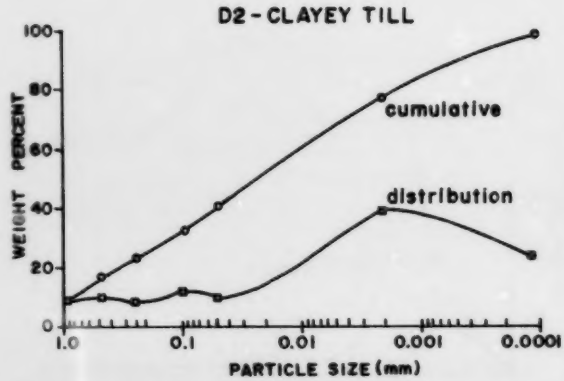


Figure 17. Mean grain-size graphs for clayey till overlying Precambrian basement rocks within the Lake Agassiz basin in the southeastern part of the map area (from Table 1)

Fluvial and Lacustrine Sands

Sand deposits, associated with outwash fans and meltwater channels such as those of the Haultain, Mudjatik and Clearwater Rivers, are scattered throughout the area but are particularly common south of the Cree Lake Moraine in the western half (Map 221A, back pocket). Fluvial and lacustrine sands south of Lake Athabasca and in the lowlands surrounding Cree Lake, the Cree River and Black Lake were deposited in the glacial lakes which occupied these areas. Most stratified sands and beach sands represent shallow-water lake deposits. In the southeastern part of the area, sands commonly found at depth in augerholes are often masked by silt, clay or peat; these sediments were deposited at depth in Lake Agassiz.

The fluvial and lacustrine sands are normally medium to fine grained and well sorted. They are nearly white to pale yellow to grey or brown at depth in some augerholes. The very pale brown to yellow to yellowish-brown colour of surface samples results from oxidation of the unsaturated sediments above the water table. The sand content of the samples ranges from about 80 percent in the southeastern part of the map area (the Lake Agassiz basin) to about 95 percent in the western part where sandstone bedrock predominates (E1 to E5, Table 1). Silt and clay content are both inversely proportional to the sand content. The grain-size distribution of samples collected in areas underlain by Precambrian basement rocks is bimodal in the sand fraction (Figure 18). This dominance of more than one grain size is not evident in individual samples (Figures 20 and 21), possibly because the mean distribution in Figure 18 is for a mixed population of sand and gravel and sand samples. The grain-size distribution of samples collected from areas underlain by sandstone is not bimodal (Figure 19), and in fact resembles the distribution for very sandy till (Figure 13). Likewise, the distributions for basement-derived sand and gravel (Figure 18) resemble those for sandy till (Figure 14). This indicates that the modes in the sand and gravel sediments may be a reflection of the mineralogy of the source material, as was the case for the tills. The resolution of these possible relationships would require more detailed investigations than are warranted in this study.

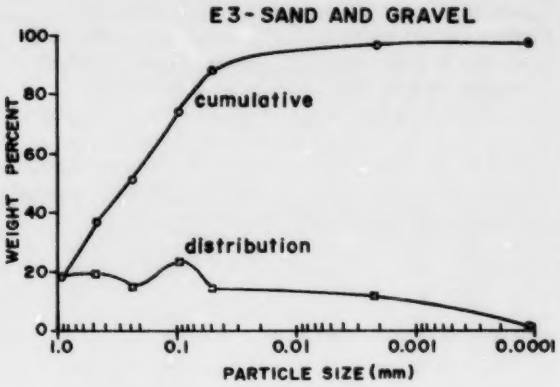


Figure 18. Mean grain-size graphs for sand and gravel overlying Precambrian basement rocks in the southeastern part of the map area (from Table 1)

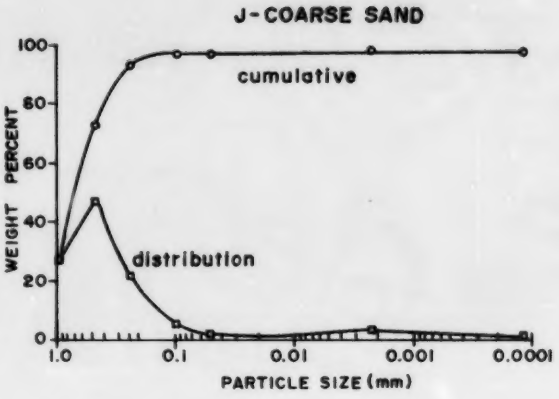


Figure 20. Typical grain-size graphs for coarse sand

Glaciolacustrine Silt and Clay

Fine-grained sediments of glaciolacustrine origin are found primarily in the southeastern part of the map area, east of Highways 2 and 102 (Map 221A, back pocket). Silt and clay deposits also occur in the southern half of the Reindeer Lake basin (NTS 64 D) and in the western half of the Lac la Ronge area (NTS 73 P). Silt is also associated with the Glacial Lake Athabasca basin, in and around the present lake, but is too limited in extent to be shown on Map 221A (back pocket). Other minor occurrences of glaciolacustrine sediments, mainly silt, are scattered throughout the remainder of the map area. The glaciolacustrine silt and clay deposits are related to ponding of water in glacial lake basins. Most were deposited in Lake Agassiz in the southeastern part of the map area. In fact, the distribution of silts and clays outlines the extent of this lake. Although many low areas are filled to a depth of over 10 m with fine lake sediments (Figure 22A, C), bedrock is very common at the surface, especially at higher elevations. The glaciolacustrine deposits, therefore, form a discontinuous mantle interspersed with bedrock, lakes, muskeg and other glacial and fluvial deposits.

Most glaciolacustrine sediments are massive, although varved silts were observed in some places (Plate 56). At depth they are olive grey to dark grey in colour, while surface samples range from light grey to olive grey to brownish grey and greyish brown. Although colour changes are not as marked as in the sands and gravels, they do indicate that weathering and oxidation have been surprisingly effective in these nearly impermeable sediments (see Appendix A for further discussion of soil development).

Table 1 gives the average compositions of silt samples (F1 to F5) and clay samples (G2, G3) from various parts of the area. The grain-size distributions shown in Figures 23 and 24 are typical of the silts and clays respectively.

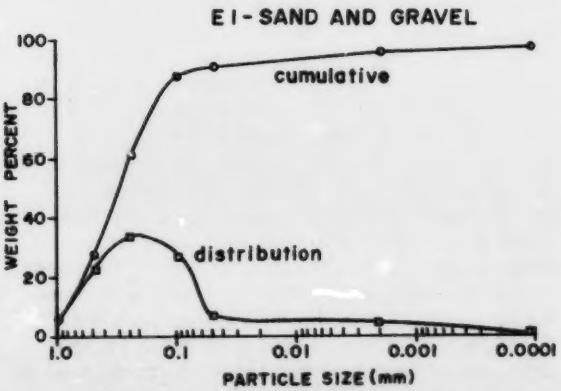


Figure 19. Mean grain-size graphs for sand and gravel overlying the Athabasca Group in the northwestern part of the map area (from Table 1)

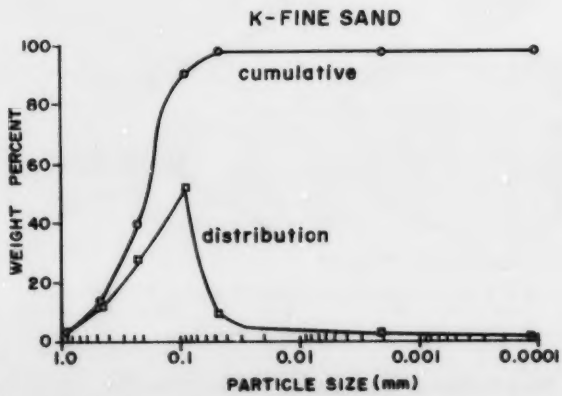


Figure 21. Typical grain-size graphs for fine sand

Quartz, feldspar and amphibole are the dominant minerals in both the silts and clays, and chlorite, kaolinite and micas (mainly illite) are the common clay minerals (Figure 15E, F, G). Schreiner and Alley (1975) reported finding montmorillonite in some samples of glaciolacustrine clay (Figure 15F). Montmorillonite is found in the Cretaceous rocks which outcrop south of the Shield in the Wapawekka Hills and other areas. It appears that the montmorillonite was carried in suspension by waters

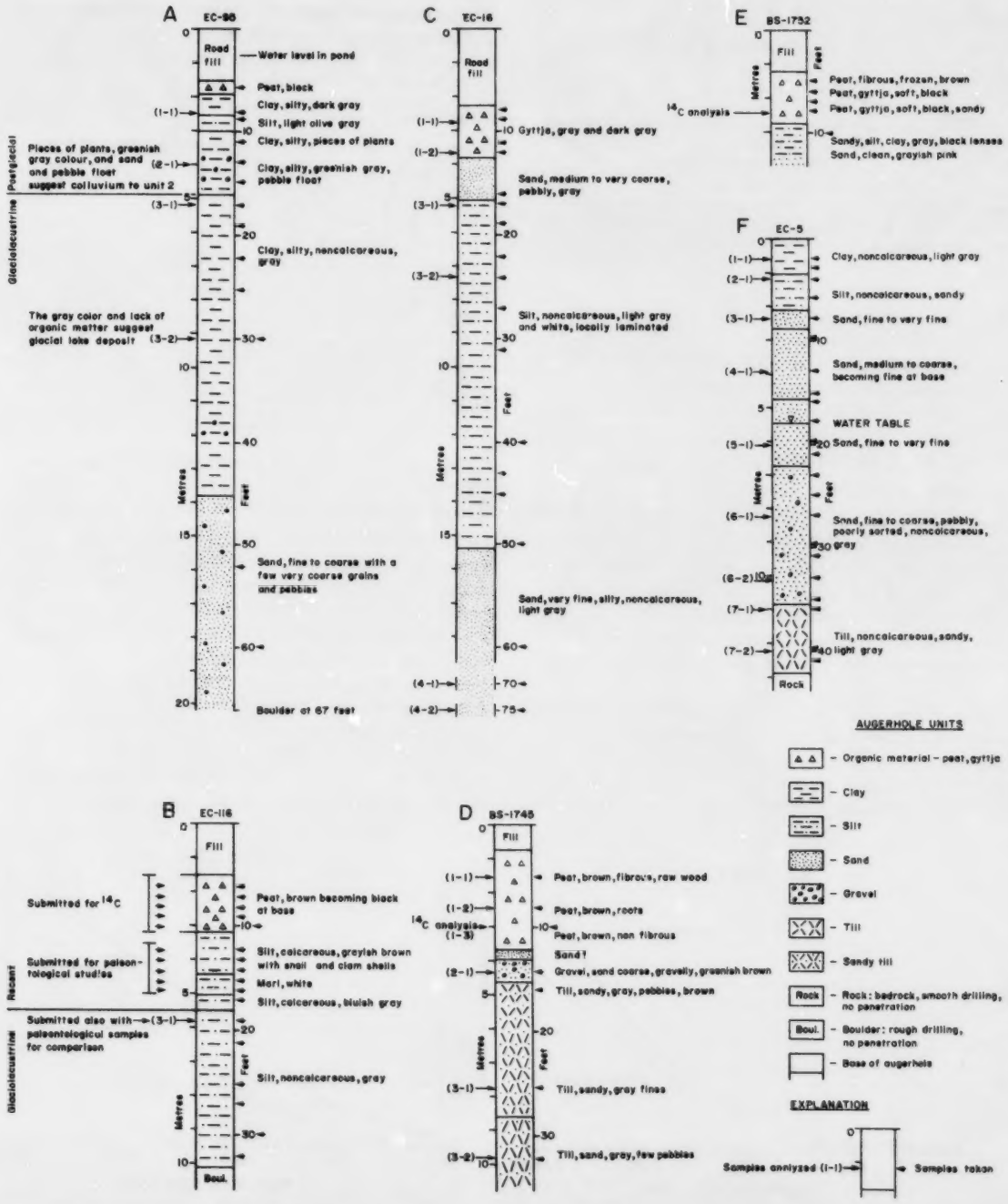


Figure 22. *Lithologic logs of lake sediments overlying till or bedrock. All show a general upward progression from glaciolacustrine sediments to recent lacustrine sediments and peat deposits. Exact locations can be obtained from the 1:250 000 scale maps (Schreiner, 1984) or the computer data files*

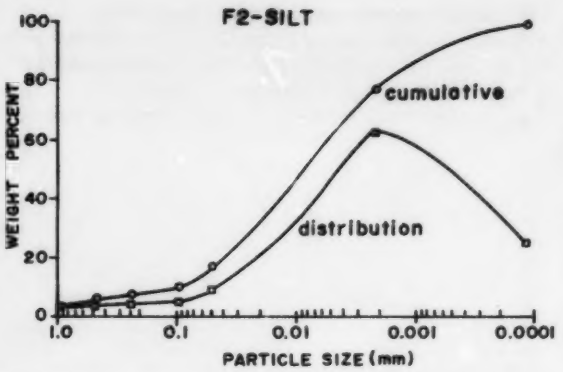


Figure 23. Mean grain-size graphs for silt overlying Precambrian basement rocks within the Lake Agassiz basin in the southeastern part of the map area (from Table 1)

flowing into the glacial lake basin from areas of Cretaceous bedrock. Because the montmorillonite was derived from several scattered sources, it occurs only sporadically and in small amounts.

Postglacial Sediments

Alluvium

Alluvial deposits are relatively small in area and uncommon on the Shield relative to glacial deposits; they are not a mappable unit at the compilation scale of 1:1 000 000 and can be shown locally only on the 1:250 000 scale maps. Most alluvial sediments occupy plains bordering present-day rivers such as the Mudjatik, Haultain, William and MacFarlane Rivers.

South of the Shield, alluvium is found along some of the larger rivers such as the Clearwater and Saskatchewan. The Clearwater River is characterized by well-developed alluvial features (e.g. plains, point bars and subaqueous sand dunes) which occur in the river course, especially on meander bends (Plate 32). When the ice sheet still covered much of the Shield, silt and clay from the plains were carried in suspension by the Saskatchewan River and deposited where the river entered Lake Agassiz to form the Saskatchewan River Delta (Plate 57). This deposit is at an altitude of approximately 380 m; the river is presently building a delta in Cumberland Lake at an elevation of about 266 m.

Colluvium

A few occurrences of colluvium were noted in the southeastern part of the map area. The grain-size distribution, with a high silt content and a sand value slightly greater than that of clay (H2, Table 1; Figure 25), is similar to that of the lacustrine silt deposits (Figure 23) and also resembles that of the silty till deposits (Figure 16). Gravel and pebbles in the sediment distinguish it from a lacustrine deposit. The mineralogy of the fine fraction of the sediment (Figure 15H) is similar to that of other sediments with high silt and clay content, including the clayey tills. These similarities reflect the incorporation of lacustrine sediments in the matrix.

Lacustrine Silt and Clay

Lacustrine silt and clay are fine-grained sediments deposited in lakes during recent times. Lacustrine deposits, the most distinctive feature of which is the presence of organic material, are common in the southeastern part of the map area where fine-grained sediments are abundant. Since many modern lake basins were previously occupied by glacial lakes, lacustrine silts and clays often overlie glaciolacustrine deposits (Figure 22A, B). Recent lacustrine deposits resemble glaciolacustrine sediments in many respects. Grain-size distribution is similar, although modern deposits generally tend to

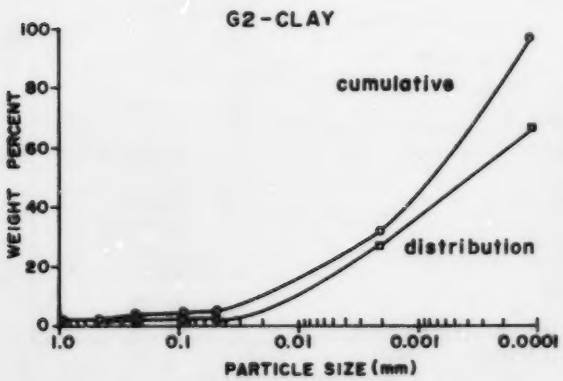


Figure 24. Mean grain-size graphs for clay overlying Precambrian basement rocks within the Lake Agassiz basin in the southeastern part of the map area (from Table 1)

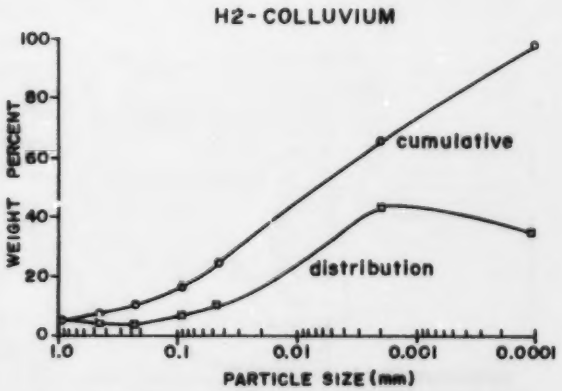


Figure 25. Mean grain-size graphs for colluvium overlying Precambrian basement rocks within the Lake Agassiz basin in the southeastern part of the map area (from Table 1)

be richer in clay, and varves predominate in glaciolacustrine sediments of high silt content. The mineralogy of the two materials is similar (Figure 15F, G). The lacustrine silts and clays may contain plant remains, shells, marl and other organic debris (Figure 22A, B); the glaciolacustrine sediments are devoid of organic materials. Wilson (1981) also reports that samples of lake cores taken for palynological studies contain abundant pollen grains, whereas glacial lake deposits are barren.

Eolian Sand and Silt

Eolian sands and silts are confined primarily to the western half of the map area, particularly south of Lake Athabasca and around Black Lake. These sediments are not sufficiently extensive to form a mappable unit at the compilation scale of 1:1 000 000 except in the Lake Athabasca area where they form the sand dune features shown on Map 221A (back pocket). Thin silt deposits, generally less than 15 cm thick, are associated with sand dunes in many parts of the area. These deposits, which resemble loess, are probably eolian in origin.

The mean grain-size distribution for a number of samples taken from various parts of a sand dune at site BS-1357 is given in Table 1 (I4). The eolian sand has a limited grain-size distribution, with most particles ranging between 0.35 and 0.1 mm in diameter (Figure 26). In eolian silt samples the secondary component is confined to the very fine sand fraction. It too reveals a very narrow grain-size

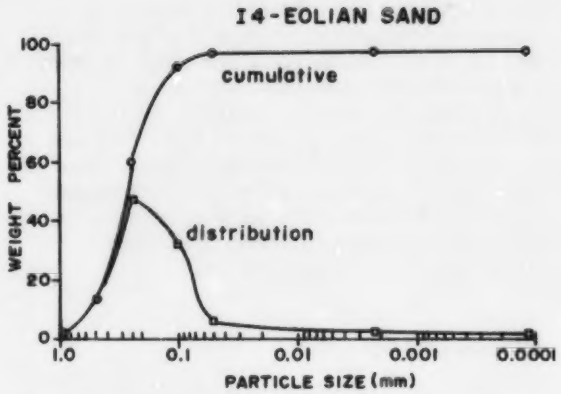


Figure 26. Mean grain-size graphs for eolian sand overlying Precambrian basement rocks in the southwestern part of the map area (from Table 1)

distribution. Grain-size properties of eolian features are also discussed by David (1981a).

Peat

Muskegs contain various kinds of peat accumulations. The peat occurring at surface is generally fibrous and brown, indicating that little decomposition has taken place. In most sections (Figure 22B, D, E), the material tends to become more decayed with depth, the end product being a well-decomposed black gyttja at the base of the bog. In some areas, the peat deposits are partially frozen (Plate 58).

Quaternary Stratigraphy and Depositional Environments

The primary purpose of this study was to map the Quaternary deposits and to determine their origin and age by brief stratigraphic investigations. Roads in the area (Figure 1) provided the means for investigating stratigraphic sections in exposures and borrow pits, and also provided access for a truck-mounted power auger to sample and investigate drift units to a maximum depth of 35 m. All information was recorded on strip logs which accompany the 1:250 000 scale maps (Schreiner, 1984) and is included in the computer data files.

Glacial Stratigraphy

Detailed investigations were carried out on sections of glacial till, ranging in thickness from less than 0.5 m to more than 10 m, from various parts of the map area. The results are summarized in this section.

Stanley Mission

During a geological investigation of the Quaternary deposits in the Stanley Mission area, two tills overlain by lacustrine silt and clay were encountered in test trenches (E.A. Christiansen Consulting Ltd., 1977). The lower, harder till is composed of grey unoxidized and greyish-brown oxidized sandy till. The upper, softer till is composed of grey unoxidized and olive-brown oxidized sandy and bouldery till. Both tills are devoid of expandable clay minerals. The presence of unoxidized till in the basal portion of the upper unit suggests that oxidation took place in the upper part of the lower unit prior to deposition of the upper till. These two units were deposited during separate glaciations and the oxidation of the lower till represents a weathering interval.

Otter Rapids

A number of exposures revealing multiple till sections are found north and south of Otter Rapids, which is where Highway 102 crosses the Churchill River (Figure 1). In one section located about 6.5 km north of Otter Rapids (BS-1730), a hard, fractured, jointed, silty sand till is overlain by a clay-rich cobbly till (Plates 59 and 60). The contact between these units is distinct and represents an erosion surface. The lower unit is more consolidated and is stained along joint fractures, indicating that it underwent weathering prior to deposition of the upper till.

Similarly, an exposure about 1.5 km north of Otter Rapids (BS-1732) reveals two till units separated by an oxidized zone which contains balls or lumps of the lower till (Plates 61 and 62). As in the case of the Stanley Mission section, a period of weathering separated the glaciations responsible for the two till units.

Key Lake

An exposure excavated in the nose of a drumlin near Key Lake in the central part of the study area (BS-2323) reveals a two-till sequence (Plates 20 and 21). The lower till unit, of which 2 m can be seen in the exposure, is very sandy and contains numerous cobbles and some large boulders. It has a greyish-pink colour and is massive and moderately hard. The upper contact is very sharp, suggesting a truncated surface. The upper till unit, about 1 m in thickness, can be subdivided into two parts. The lower part, composed of a moderately hard sand-rich till, is pinkish grey and contains fewer boulders and cobbles than the lower till unit. The contact with the upper part is poorly defined, and varies from an undulating surface to a gradational zone where no definite division can be seen. The upper material is loosely packed and rich in sand; boulders are common and the structure appears to be massive. The yellow-brown colour is likely due to oxidation. The composition and stratigraphy suggest that the lower unit may be a lodgement till deposited by flowing ice. Rejuvenation of flow appears to have truncated the lower unit and deposited a second lodgement till. The receding ice then deposited the ablation till. This multiple till section suggests that more than one glaciation has affected the area.

Western Sections

Thick sections of till were encountered in augerholes on the west side of the map area. An exposure located along Highway 155 just north of the Clearwater River (BS-1757) consists of approximately 4 m of pink sandy till with cobbles overlain by more than 1 m of yellow silty sandy till with boulders (Figure 27A). A distinct contact separates these two units. A second exposure 8 km to the north (BS-1743) consists of 1 m of pinkish-grey sandy till with pebbles and cobbles overlain by about 2 m of brown sandy till with pebbles (Figure 27B). The upper unit also contains 'balls' or lumps of the pinkish-grey sandy till, indicating that the ice incorporated some of the pre-existing lower till into the upper unit.

Other till sections, many greater than 15 m in thickness and one (BS-1742) greater than 35 m, are recorded in the logs of the western half of the area. Separation of these sections into units is difficult due to their uniformity. This is a result of derivation from the relatively uniform rocks of the Athabasca Group. Grain size is remarkably similar throughout the sections and, although colour changes and the quantities of pebbles, cobbles and boulders give some evidence of different deposits, such criteria are not reliable distinguishing characteristics.

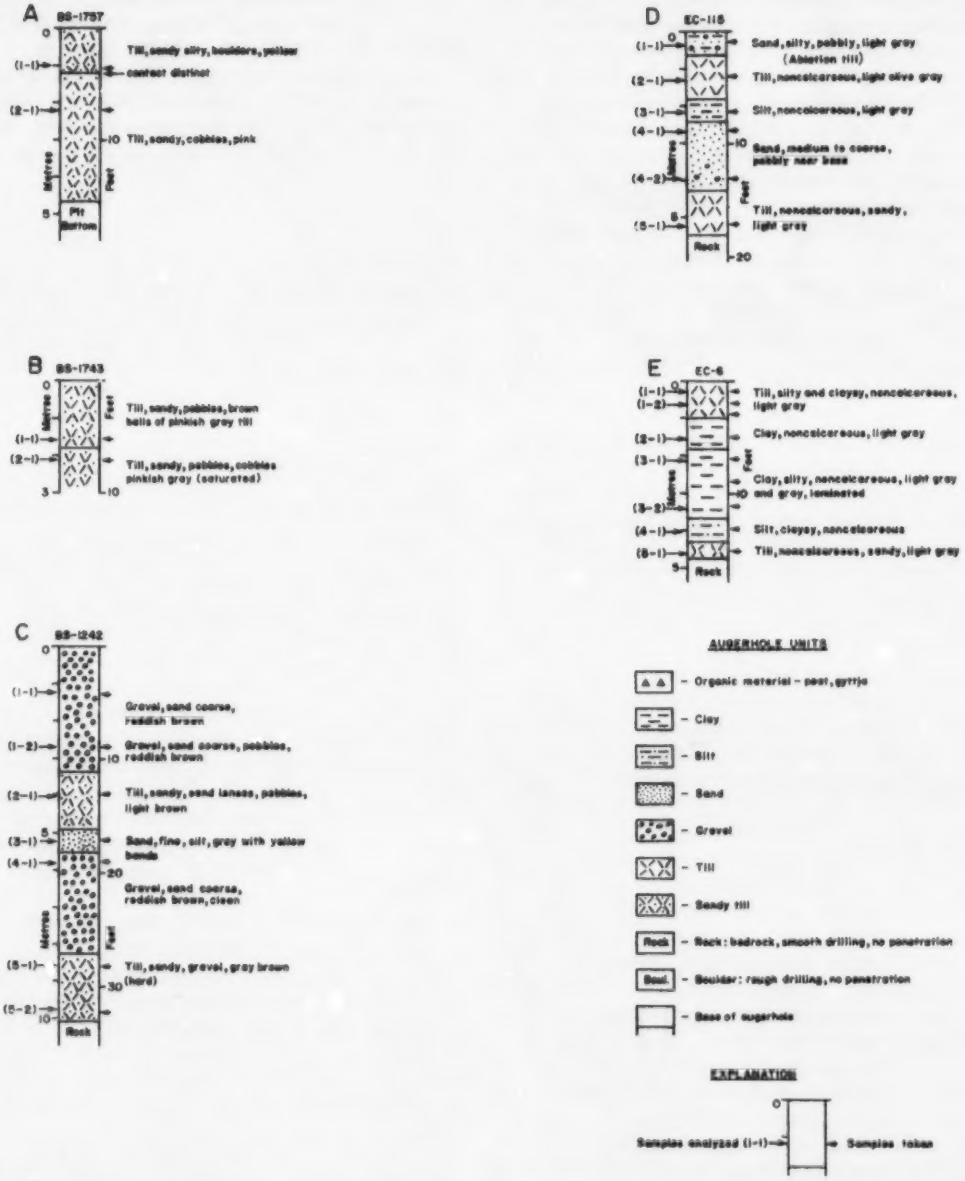


Figure 27. *Lithologic logs of drift. Exact locations can be obtained from the 1:250 000 scale maps (Schreiner, 1984) or the computer data files*

Cluff Lake

A trench excavated in drift east of Cluff Lake in the northwestern part of the study area (BS-2343) reveals several till units. The exposed portion of the lower unit consists of more than 2 m of very sandy till containing scattered cobbles and boulders; the colour is greyish pink to pinkish white and the unit is massive and moderately hard. The upper contact is sharp, indicating an erosional surface. The middle till unit is similar but more yellow in colour; it is 1 m thick in the southern part of the trench and pinches out toward the north. The upper contact is again sharp, suggesting a truncated surface. The upper unit, which is commonly less than 1 m thick, can be subdivided into two parts. The lower part is composed of a hard, yellowish-brown, silty sand till which contains numerous cobbles and pebbles but few boulders. An undulating to gradational contact separates it from the upper part, which is soft, loosely packed and more sandy in texture.

The composition and texture of the lower till unit suggest that it is lodgement till derived from the Athabasca Group sandstone. The middle unit, because its characteristics are similar, could be a lodgement till or an ablation phase of the lower till. The distinct contact between the two units indicates that the middle till was deposited by actively flowing ice. The upper unit is much more mafic in composition than either of the lower units, indicating that this till was derived from Precambrian basement rocks. The distinct lower contact again suggests that flowing ice deposited the lower part of this unit. The soft sandy nature of the upper part and the gradational undulating contact between the upper and lower parts suggest that the upper material is an ablation till.

This multiple till sequence indicates that more than one glaciation has been active in the Cluff Lake area. The difference in source material suggests a change in ice-flow directions. The sandstone-derived till was likely deposited by ice moving from the northeast across sandstone bedrock. The basement-derived till was probably laid down by ice advancing from a more northerly direction across the basement rocks exposed north of Cluff Lake. Alternatively, the earlier glacier may also have advanced from the north, stripping off the last of the sandstone cover to expose the basement rocks and incorporating the debris into the lower tills. Continued erosion would then have provided basement material for the upper till unit.

East of Uranium City

A recent exposure was examined along the road to Fredette Lake east of Uranium City (BS-2743). The lower unit, more than 3.5 m in thickness, is a red, silty sand till which grades from coarsely laminated at the top to massive at the base. This till is overlain by about 1 m of stratified sand and gravel which ranges from yellow through brown to grey. Blocks of the underlying till occur at the base of this stratified unit. The upper unit is a soft, brown, silty sand till commonly less than 0.6 m thick. The lack of distinct contacts between the units suggests that the lower till may be a lodgement till and that the stratified sand and gravel unit and the upper till were deposited by ablation of the ice mass.

Peter Lake

Samples were obtained by augering through 10 m of overburden to bedrock at mile 90 (km 144.8) on Highway 105, just north of Peter Lake (BS-1242; Figure 27C). This augerhole revealed the following units (from bottom to top): 1.8 m of hard, sandy, grey-brown till; 2.6 m of clean, reddish-brown gravel; less than 0.6 m of fine, grey, silty sand; 1.5 m of brown sandy till containing lenses of pure sand; and over 3 m of reddish brown gravel with coarse sand and pebbles.

The sequence suggests that ice deposited the lower till and then, after retreat of the ice sheet, first the gravel and then the sand were laid down by meltwater. A readvance led to the deposition of the second till, into which lenses of the lower sand unit were incorporated. The surficial gravel was deposited after the final retreat of the ice. Two glacial cycles are indicated.

Wollaston Lake

An exposure along Highway 105 near Hidden Bay of Wollaston Lake (BS-2546) consists of a hard, massive, grey, sandy lodgement till containing abundant boulders, cobbles and pebbles, and overlain by a soft, loosely consolidated, yellowish-brown, sandy ablation till (Plate 63). There is a distinct contact between the two units. A thin, spordic layer of silt, probably of eolian origin, covers the upper till unit.

Rabbit Lake

Multiple till units are common at the Rabbit Lake Mine near Wollaston Lake, both in the open pit walls and in drillholes throughout the area (Geddes, 1980). At the mine site, the upper of two till units is commonly covered by a graded bed of silty sand, which is in turn overlain by the layer of organic matter deposited on the bottom of the lake.

In two drillholes, organic material was collected from below a till unit for radiocarbon dating. One hole near Michael Lake revealed wood and other organic material beneath 10 m of grey, silty, pebbly till. Similar till was found beneath the organic material. Bedrock was encountered at a depth of 12 m. The second hole, near Collins Bay, produced organic-rich silty material from a depth of about 9 m; it lay beneath a grey till similar to that encountered in the first hole. Sorted material was found below the organic-rich silt. Both of these organic samples (S-1743, S-1744, Table 2) gave radiocarbon dates beyond the capability of the method (i.e. greater than 34 000 years B.P.). This organic material was deposited during an interglacial period, probably the most recent, in which case the overlying till was deposited by the last major glacial advance.

Deschambault Lake

Several stratigraphic sections, particularly in the southeastern part of the study area, show a layer of till overlying fluvial or lacustrine sediments. A section near Deschambault Lake which exhibits this sequence (EC-115; Figure 27D) consists of (from bottom to top): 1 m of sandy till; 1.5 m of sand which grades from pebbly at the base to medium grained at the top; less than 0.5 m of silt; and 2 m of till, which can be divided into a lower, light olive-grey, non-

calcareous till composed of 63 percent sand, 30 percent silt and 7 percent clay, and an upper light grey till composed of 74 percent sand, 25 percent silt and 1 percent clay. The bimodal nature of the sand fractions confirms that the deposit is till. The lower and upper parts are believed to be lodgement and ablation till respectively.

Mirond Lake

An exposure on Highway 135 south of Pelican Narrows (BS-877) shows approximately 1 m of sandy till overlying stratified sand and gravel (Plate 64). A distinct contact separates the two units.

Missinipe

An exposure in a gravel pit on Highway 2 about 10 km south of Missinipe (BS-2) shows a thick section of stratified gravel and sand which grades upward into silt. This material is overlain by about 1 m of till (Plate 65), the lower part rich in silt and clay and containing large boulders, and the upper part more sandy and loosely packed. This unit may comprise both lodgement and ablation till. The contact between the till and the underlying silt is very distinct.

The sections at Deschambault Lake, Mirond Lake and Missinipe reveal that a glacial cycle was followed by a period of retreat during which fluvial gravel, sand and silt were deposited. The ice then readvanced and covered these sediments with a layer of till.

Jaysmith Lake

A 5 m deep augerhole near Jaysmith Lake (EC-6; Figure 27E) revealed the following sequence (from bottom to top): 0.4 m of sandy till; 3.3 m of lacustrine sediments which grade upwards from clayey silt through silty clay to clay; and 1.0 m of silty, clayey till which contains more than 50 percent clay. The lacustrine sediments and the upper till both contain montmorillonite, the origin of which was discussed in the section on "Glaciolascustrine Silt and Clay". The high content of silt and clay in the till and the presence of montmorillonite and some carbonaceous material suggest that the till has incorporated some of the underlying lacustrine deposits. A similar clay-rich till (see "Clayey Till" section), which occurs sporadically on surface throughout the Lake Agassiz basin, indicates that the ice readvanced into the basin after the lacustrine sediments were laid down.

Rabbit Creek

A composite section of two augerholes (BS-2759, BS-2760) drilled at Rabbit Creek, about 25 km south of La Ronge on Highway 2, also indicates a readvance of ice over Lake Agassiz sediments. The section, from bottom to top, is as follows: greater than 20 m of dark grey, hard silt which contains layers of till less than 1 m thick; nearly 7 m of brown sandy silt till; 2 m of calcareous, soft, brown silt; about 1 m of soft, brown, oxidized, silty till; slightly less than 3 m of clay grading upward into silt and fine sand.

The thick lower silt unit was likely deposited during a high-level phase of Lake Agassiz. The thick overlying till must have been deposited by a readvance of ice which incorporated some of the silt into the till. The clay, silt and sand sequence at the top of the section was deposited in Lake Agassiz after the ice had receded from this area. Other sections in this vicinity also suggest the readvance of ice and the presence of Lake Agassiz before and after the readvance. However, all of these sections require more detailed investigation and correlation in order to accurately determine the true sequence of events.

Proglacial Stratigraphy

Ice-contact deposits are exposed along the roads in the eastern half of the area, especially along Highway 2 and 102 from La Ronge to McLennan Lake and along Highway 135 north and south of Pelican Narrows. Many of the occurrences examined show a complex relationship of different sediments. An exposure north of McLennan Lake (BS-1729) reveals layers of sandy till intermixed with beds, lenses and pockets of sand, silt and stratified sand and gravel (Plate 66). A borrow pit east of Highway 2 on the road to Stanley Mission (BS-1717) exposes a sorted and stratified gravel overlain by a sequence of stratified sand and silt and a thin layer of sandy gravelly till. A large block of hard, grey, massive till within the gravel is underlain by gravel and fine sand (Plate 67). An exposure along Highway 135 (BS-873) consists of dirty gravel overlying a silt layer which contains lenses or blocks of clay. The variable nature of the stratigraphy in these deposits suggests an environment, such as an interlobate area or eskerine-kame complex, where sediments were deposited in contact with an ablating ice margin.

Glaciofluvial deposits are revealed in augerholes and roadside exposures in many places throughout the study area, particularly around Uranium City. The occurrence of thick, coarsely stratified sand and gravel deposits containing cobbles and boulders (Plate 68) at one site east of Uranium City (BS-1892) suggests a high-energy meltwater environment. Similar deposits in the same area indicate that water flowing from the ice was confined to ice-walled channels or bedrock valleys where the coarse sediments were deposited. Other deposits were found to be finer and possess better stratification, occassionally with forset beds being developed (Plate 69). These sediments were also carried by meltwater but commonly formed deltaic deposits where the meltwater entered Glacial Lake Athabasca.

Fluvial deposits associated with the rivers of the area are seldom exposed. One exposure along the Black Lake road (BS-2292) consists of well-stratified fine sand and silt (Plate 70). Another exposure near the William River (BS-2740) reveals well-stratified fine sand containing ripple marks and other stratification features such as cross-bedding (Plates 71 and 72). Both are examples of fluvial deposition where a river carrying sediment enters a lake, in this case Glacial Lake Athabasca.

An outstanding characteristic of the proglacial drift within the Lake Agassiz basin is a 'fining upward' tendency in the sequence of sediments. The typical sequence, as shown in Figure 22F, consists of till deposited on bedrock and overlain by coarse gravel grading upward to sand. Silt covers the sand, and clay comprises the uppermost part of the section. A similar sequence occurs in a section of Lake Agassiz sediments near Brabant Lake (Plate 73). Fine sand is overlain by varved silt, the varves being thick and flat lying at depth but thinning toward the surface and becoming contorted. The silt grades upward into an amorphous clay deposit.

The 'fining upward' sequence of sediments resembles the transgressive onlap sequence produced by the advance of a water body across a land surface. As meltwater discharged from the receding ice front, it carried debris into the ice-dammed Lake Agassiz. Coarse material was deposited in the area near the ice front; finer sediments were carried farther out into the lake. As the ice front receded, finer sediments were continually being deposited over coarser material.

Lacustrine clay, silt and sand are uncommon outside the Lake Agassiz basin except in the vicinity of Lake Athabasca. An augerhole drilled through the ice about 1.5 km from the south shore of Lake Athabasca north of Ennuyeuse Creek (BS-2353) revealed over 19 m of silt and clay. These sediments were pinkish grey in colour, rubbery in texture and devoid of organic material, suggesting that they were glacial lake sediments. Greater than 15 m of fine, brown, glaciolacustrine sand was encountered in each of two augerholes drilled south of the lake (BS-2355, -2356).

At site BS-1890 near Uranium City, approximately 1 m of white clayey silt overlies more than 3 m of pink sandy till. Silt is commonly exposed in low-lying areas around Uranium City. Silt is found sporadically along the Fond du Lac River and at Black Lake. An exposure along the Black Lake road (BS-2318) reveals about 2 m of fine lacustrine sediment. Fine sand is overlain by silt, which is in turn overlain by silty clay (Plate 74). All of these fine lacustrine sediments were deposited in Glacial Lake Athabasca.

Postglacial Stratigraphy

Modern lacustrine silt and clay deposits occur in some parts of the area, mainly in the Lake Agassiz basin; they commonly overlie glaciolacustrine sediments. This type of sequence, in which 2 to 3 m of recent sediments overlie glacial lake deposits, is shown in sections EC-95 and EC-116 (Figure 22A, B). In section EC-95, the lower part of the recent material may be a clay-rich colluvial deposit, whereas the upper part is clay. In EC-116, the recent sediments consist of grey silt with some marl and other organic material.

Peat, generally 1 to 2 m in thickness, forms the top of many sections (Figure 22B, C, D and E). Several holes drilled through road beds into peat bogs to obtain samples for radiocarbon age dating revealed that, on average, the peat deposits were compressed to one-third of their original thickness by the weight of the road fill. Results of the radiocarbon dating are given in Table 2.

Eolian sands and silts, although found only locally, overlie nearly all types of other sediments in the western half of the area. The sand dunes and associated silt migrated indiscriminately across fluvial deposits, glacial till and even muskeg. The silt is commonly found as an elongate blanket extending downwind from a dune field. One site investigated by P.P. David and the author (BS-1355) reveals the stratigraphy of the eolian silt deposits. About 100 m downwind from a dune field near Careen Lake, a layer of loess (silt) approximately 30 cm thick overlies a gravelly till. The contact of the two materials is marked by a flat sandstone boulder, the upper part of which is slightly polished and etched by wind. This sequence indicates that the boulder resting on the till was sand blasted for a short time before being buried in loess which must have been deposited contemporaneously with the formation of the dunes.

Thin eolian silt deposits cover till at a site (BS-2546) near Wollaston Lake (see p. 40). This type of thin eolian veneer was also noted in the Cluff Lake area. The scattering of sites indicates that eolian activity was widespread and involved nearly all of the study area.

In the active dune areas south of Lake Athabasca, eolian sand overlies glaciolacustrine or glaciofluvial sediments, or occasionally till. Outside the active sand areas, such as at Pederson Lake (74 N-2) eolian silt is commonly found overlying sandy till deposits.

Stratigraphic Correlation

Stratigraphic correlation of drift units in the Precambrian Shield is difficult. The rugged terrain, a reflection of bedrock relief, provides many basins where drift units may accumulate and provide a

nearly continuous record of events, whereas many hills are stripped bare, exposing bedrock. These uplands commonly separate the lower lying areas and prevent direct correlation of drift units over large areas.

Correlation of till units using diagnostic parameters is also difficult on the Shield. The Precambrian basement rocks vary greatly in lithology over short distances, commonly hundreds of metres (see Figure 2). The glacial till, composed of comminuted bedrock and reworked material from earlier drift units, therefore also varies in composition over short distances. In contrast, the relative homogeneity of sediments in the Athabasca Group means that the till derived from these sediments is also uniform in composition. Successive glaciations eroded the same rocks, resulting in multiple till units that are very similar.

During this study, organic material of potential use in radiocarbon dating, primarily peat, was collected almost entirely from the surface and thus would not yield dates that were meaningful in terms of glacial stratigraphy. The only organic material found within or between drift units, collected at the Rabbit Lake Mine, was too old to date by radiocarbon analysis. This lack of datable material prevents correlation on a time stratigraphic basis.

Correlation of till units may be possible on a local scale. For example, two sections north of Otter Rapids (BS-1730 and BS-1732) can be correlated to a certain extent. The lower till units in both sections are hard and compact, and have similar grain sizes and degree of oxidation. These two units can therefore be correlated on lithologic parameters in the same manner as rock stratigraphic units. At the Key Lake site (BS-2323), the distinct contact separating tills can be traced locally.

Colour changes, heavy mineral assemblage and other characteristics may sometimes be used to correlate units over short distances. At Cluff Lake, the tills derived from the basal sandstone and from the upper basement can be traced in trenches over short distances based on colour and composition. The contrasting lithology of the two bedrock sources that makes this correlation possible is not a common occurrence in other parts of the study area. At Wollaston Lake, tills have been correlated in drillholes on the basis of colour, lithology and heavy mineral assemblage (Geddes, 1980). For stratigraphic correlation, numerous test holes are required and detailed analysis of samples is essential. Such work may permit correlation of drifts over small areas, such as within a mining property.

Stratigraphic Interpretation

Although correlation in many places is complicated or impossible, the stratigraphic sections examined reveal a great deal about the sequence of events and types of processes that occurred in the area. Multiple till sections in which the lower till units are oxidized indicate that more than one glaciation has occurred and that these glacial advances were separated by intervals of weathering, suggesting relatively long periods of ice-free conditions. The buried organic material at Wollaston Lake indicates that the last glacial advance was preceded by an interglacial period.

The truncated contacts between tills and the incorporation of lumps or 'balls' of lower till into the upper unit also suggest successive ice advances. A lodgement-ablation sequence is suggested when the lower part of a till is consolidated and the upper part is loose and more sandy. Tills with differing lithologies indicate different source materials and imply either a change in ice-flow direction from one glacial advance to the next or glacial stripping of bedrock between glaciations.

The intertill deposits reveal that glacial deposition of till was followed by fluvial deposition of gravel and sand as the ice melted. These sediments were in turn covered by glacial till, probably deposited by a readvance. The upper till which occurs in a number of these sections is consistently thin, only about 1 m thick, and ranges from sandy to silty to clay-rich. The matrix seems to correspond to the underlying sediments in most places. The lower contact of the unit is generally distinct. The clay-rich upper till is widely distributed, primarily within the Lake Agassiz basin, suggesting that it is the result of a readvance into the basin. The extent and relationships of this readvance were discussed by Schreiner and Alley (1975). The advancing ice presumably eroded the pre-existing sediments, resulting in truncation of the drift units. The ice which overrode the fluvial or lacustrine sand, silt and clay incorporated these sediments into the upper till. The till matrix, therefore, commonly resembles the underlying sediments and is separated from them by a distinct contact.

Generally, the higher the clay content of the till, the fewer clasts it contains and the more it resembles a lacustrine deposit. Such tills may be waterlaid (Dreimanis, 1976), having been let down from beneath a floating ice mass. Ice in the Lake Agassiz basin is therefore believed to have been partly afloat, giving rise to the deposition of the clay-rich tills.

Langford (1975, 1977) explained the clay-rich till and other till-like deposits observed in exposures and drillholes along the Churchill and Reindeer River valleys as flow or slump deposits. The ice-contact deposits and outwash along Highway 135 near

Pelican Narrows, which were also noted by Langford (1975) and Shawinigan Engineering Company Limited (1973), are likely to contain this variable stratigraphic sequence, with tills and intertill deposits intermixed. This zone is probably an interlobate area and may extend farther north along the Churchill River toward the Reindeer River valley (Figure 1). Many of the till-like deposits and the complicated stratigraphy may have resulted from the deposition of ice-contact deposits in this interlobate zone. Some of the more recent material could be the result of mud flows or slumps, as suggested by Langford (1977).

The author, however, maintains that the uppermost diamictic unit, which in many sections overlies stratified or lacustrine sediments, is a till. If this is the case, the tills, whether or not they are flow tills, must have been deposited during a readvance which covered a wide area because they overlie drift deposits in an extensive area.

The 'fining upward' sequence of lake sediments suggests a retreating ice mass that supplied sediment to the Lake Agassiz basin. The lake transgressed across the land, following the retreating ice. This process of lacustrine sediments filling the basin as the ice receded occurred in a number of other cases, such as Glacial Cree Lake and Glacial Lake Athabasca. As the flow of meltwater diminished and the glacial lakes receded, modern lake sediments were deposited in the deeper basins. Peat accumulated in shallow depressions as muskeg. In the drier regions, particularly the western half of the study area, strong winds were actively reworking sand into dunes, and loess was laid down as a blanket covering pre-existing deposits.

Quaternary History

Continental glaciers advanced and retreated across the study area several times during the last two or three million years. Although multiple tills occur, the scarcity of stratigraphic information prevents an interpretation of glaciations other than the most recent (Wisconsinan). The various stages of this glaciation are discussed and shown on sketch maps (Figures 28 to 34).

The account presented here is a continuation of the deglaciation history of southern Saskatchewan and adjacent areas (Christiansen, 1979). The criteria on which the history of deglaciation is based include glacial deposits, landforms, drainage, stratigraphy and radiocarbon dates. The deposits and landforms indicate the environments, while the drainage, stratigraphy and radiocarbon dates provide methods of correlating these environments.

The phases of deglaciation merely portray a chronologic sequence of events. Whether the ice frontal positions shown represent an active or stagnant ice margin is generally not known. Landforms, such as end moraines, which define an ice margin are not common north of the Cree Lake Moraine. Therefore most ice positions shown coincide with a particular glacial drainage pattern.

The dating of ice frontal positions in Canada has been done by Prest (1969). Dates have been applied to the various levels of Lake Agassiz by Elson (1967). Christiansen (1979) has applied dates to ice frontal positions in southern Saskatchewan and as far north as the Cree Lake Moraine. Although some discrepancies exist among these dates, they are considered here, particularly those of the Cree Lake Moraine and the Campbell phase of Lake Agassiz. More recently dates of ice position and Lake Agassiz levels have been assigned in Teller and Clayton (1983). The dates presented here correspond to this more recent work. Radiocarbon dates for the Saskatchewan Shield are from surficial material and only provide minimum ages for deglaciation. Specific dates have been applied to the phases of deglaciation shown north of the Cree Lake Moraine, but they are highly speculative.

Deglaciation History

Phase 1

Phase 1 of the deglaciation history of the study area (Figure 28) corresponds to Phase 8 of the deglaciation history of southern Saskatchewan and adjacent areas, as described by Christiansen (1979). During this phase, water drained through the Beaver River into Glacial Meadow Lake, which occupied an elongated basin in the western half of the area. This lake drained through the Clearwater Spillway into the Athabasca Spillway in Alberta, which in turn drained into Glacial Lake McConnell (Christiansen, 1979). A delta was formed where the Beaver River entered Glacial Meadow Lake. A radiocarbon date (Table 2, no. 2) along the Waterhen River suggests that Glacial Meadow Lake drained more than 9935 years B.P.

Lake Agassiz, to the southeast, is shown at the early Campbell waterplane of Elson (1967). At this time the Saskatchewan River began building the Saskatchewan Delta. A radiocarbon date of 10 265 B.P. (Table 2, no. 3) at the base of eolian deposits on the Saskatchewan Delta suggests that Lake Agassiz receded from the Campbell waterplane prior to this date. It is possible, however, that the eolian deposits are contaminated with old carbon and that the date is too old. Clayton (1983) suggests that Lake Agassiz fell below the Campbell level a few hundred years after 9900 B.P., but Klassen (1983) adopts a date of approximately 10 000 B.P. for the end of the Campbell phase. The latter date is accepted as a reasonable approximation until new evidence for the area is obtained or confirmation of existing dates occurs.

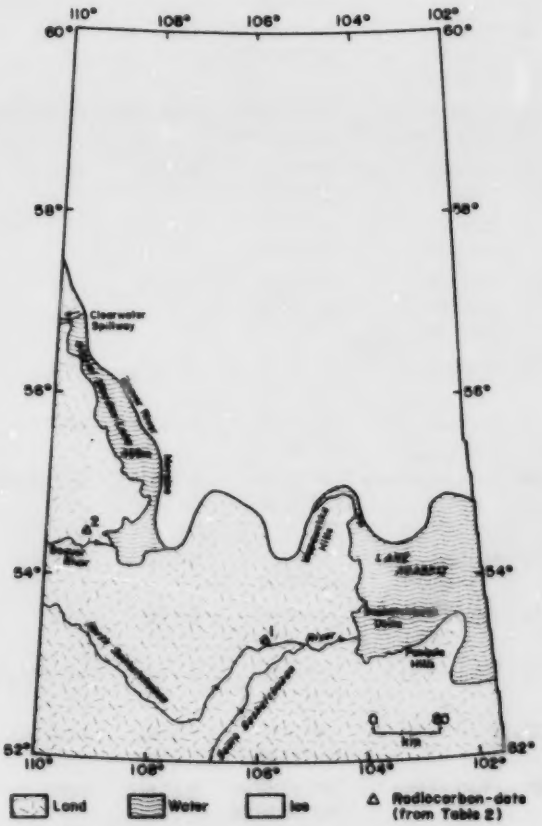


Figure 28. Deglaciation history (Phase 1), approximately 11 000 to 10 000 years B.P. (from Christiansen 1979, p. 930)

Table 2. Significant Radiocarbon Dates

Site No.	Site Name	Location	Sample	Material	Years B.P.	Comments	References
1	Prince Albert	53°14'N 105°44'W	GSC-648	organic sand	11 560±640	base of pond deposit, 600-620 cm below bottom of pond	Lowden et al. (1967)
2	Waterhen River	54°27'N 109°12'W	S-964	marly silt	9935±170	10 m deep at base of marly silt, with wood and shells	
3	Nipawin	53°18'N 104°04'W	S-2166	carbonaceous, sandy silt	10 265±585	10 m deep at base of eolian sand covering fluviolacustrine sediments	
4	Deschambault	54°55'N 103°23'W	S-1065	peat	5900±80	base of peat overlying recent and glaciolacustrine silt	
5	Cycloid Lake (A)	55°15'N 105°16'W	GSC-643	basal gyttja	8520±170	gyttja overlies organic brown clay and inorganic clay	Lowden et al. (1967) Mott (1973)
6	Lake A	55°20'N 105°03'W	S-1504	organic clay	8055±155	depth 350 cm in pond deposits	Wilson (1981)
7	Naniskak Lake	55°26'N 104°56'W	S-1502	organic clay	7680±90	depth 450 cm in pond deposits	Wilson (1981)
8	Wheeler Creek	55°35'N 104°47'W	S-949	gyttja	7305±95	base of gyttja overlying sand and silt	
9	South of Cree Lake Moraine	55°53'20"N 104°04'30"W	GSC-1446	gyttja	8640±240	gyttja overlying silty clay over coarse bouldery gravel	Mott (1971)
10	North of Cree Lake Moraine	56°07'30"N 104°24'20"W	GSC-1466	organic silt	8230±250	depth 562-572 cm in pond deposits	Mott (1971)
11	Junction Hwys. 102 and 105	56°15'N 103°35'W	S-1231	peat	6420±115	in palsa, 2 m deep above silt	
12	Mile 25 (km 40), Hwy. 105	56°37'N 103°36'W	S-1070	frozen peat	6910±100	base of peat overlying sand and silt	
13	Mile 100 (km 161), Hwy. 105	57°29'N 103°58'W	S-1223	peat	5660±65	base of peat overlying sandy till	
14	Sholte Lake	57°40'N 109°28'W	S-1487	peat	6980±95	base of peat overlying sandy silt	
15	Carswell Lake	58°31'N 109°24'W	S-1659	peat	4685±70	base of peat overlying sand and till	
16	Lake Athabasca	59°02'N 108°52'W	S-2055	woody peat	7755±135	base of peat depcsit at 1.75 m overlying sand	J.S. Rowe, (pers. comm.)
17	Michael Lake	57°52'N 103°55'W	S-1743	wood	>34 800	10 m below surface under till	
18	Rabbit Lake	58°12'N 103°42'W	S-1332	peat	8335±160	base of peat in lake bottom above till	
19	Collins Bay	58°17'N 103°37'W	S-1744	organic silt	>35 600	9 m below surface under till	
20	Black Lake	59°08'N 104°53'W	S-1560	peat	6855±110	in palsa, 1.2 m below surface above ground ice	
21	Phelps Lake	59°10'30"N 103°06'20"W	S-1746	peat	5850±70	3 m below surface above frozen peat	

Note: Radiocarbon sites are located on Figures 28 to 34.

Phase 2

By Phase 2 (Figure 29), the ice had retreated north to a position in the eastern part of the area that closely corresponds with that shown by Prest (1970, Figure XII-15, position 10 900 B.P.). In the northwestern part, the ice position nearly coincides with the Cree Lake Moraine. Lake Agassiz invaded as far west as the Mudjatik Channel. As stated by Christiansen (1979), the absence of glacial lake sediments on the surface west of this point suggests that Lake Agassiz did not extend to the Clearwater Spillway as speculated by Elson (1967, p. 83). Apparently, the lake level had fallen below the Campbell level or isostatic rebound raised the land before the lake invaded the area to the west along the Churchill River. Christiansen (1979) postulated a reversal of drainage in the Clearwater Spillway and through the Churchill Spillway to Lake Agassiz. If this reversal did occur, it likely took place during this phase of the lake. The lake level as shown is marked by beaches along the Pasquia Hills north to the Wapawekka Hills, as well as south of Lac la Ronge, and by deltas formed where the Mudjatik, Haultain, Belanger and Foster Meltwater Channels entered the lake.

The ice position and lake level shown in Figure 29 nearly correspond to those shown by Elson (1967, Figure 8), which represent a late Campbell level of Lake Agassiz at 9500 B.P. The ice position and lake level also correlate closely with Phase 1 of Klassen (1983) at 9500 B.P., which represents a level of Lake Agassiz after the Campbell phase. Whether Phase 2 represents a late Campbell level or a later stage of Lake Agassiz is not known for certain at this time.

Phase 3

During Phase 3 (Figure 30), the ice front stood at the Cree Lake Moraine, which corresponds to the ice-frontal position indicated by Prest (1970, Figure XII-15) for 10 000 B.P. The lake level in the south is marked by beaches along the Pasquia Hills, the Wapawekka Hills, and the highlands between these hills. In the north, raised beaches are located at Hunter Bay, with the highest beach at Macoun Lake (Johnston, 1978). The Foster Channel continued to form a delta where the meltwater from the ice to the north entered the lake. In the Pelican Narrows area, south of Macoun Lake and east of Hunter Bay, lake sediments are not commonly found above an

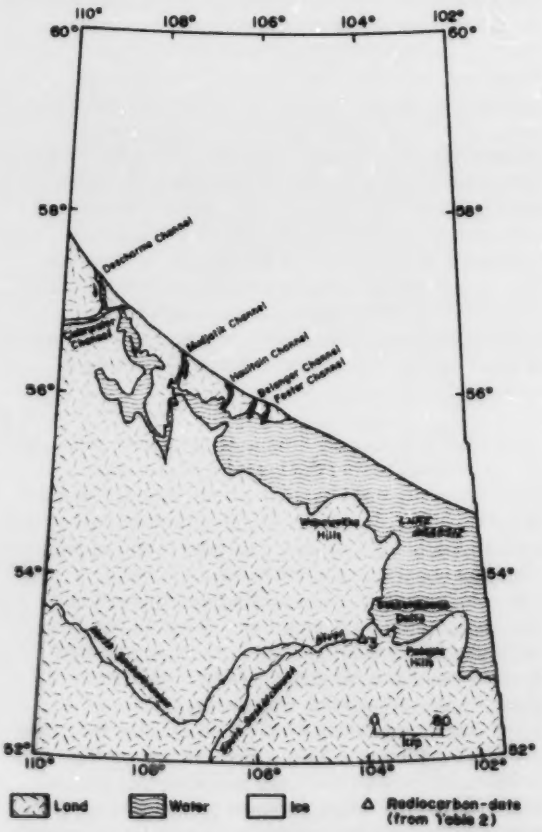


Figure 29. Deglaciation history (Phase 2), approximately 10 000 to 9500 years B.P.

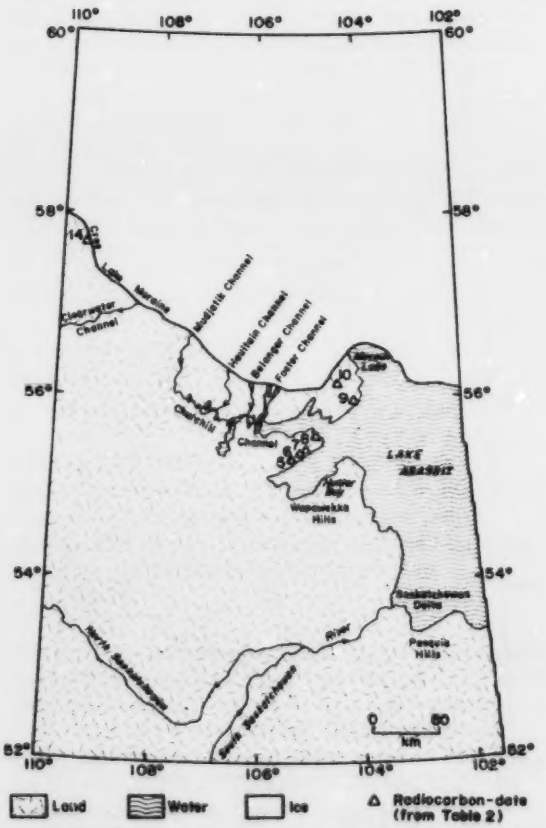


Figure 30. Deglaciation history (Phase 3), approximately 9000 years B.P.

elevation of 400 m and are absent above 427 m, indicating that the lake level lay between these elevations, as discussed by Langford (1977).

A number of radiocarbon dates (Table 2, nos. 5, 6, 7, 8, 9, 10 and 14) indicate the minimum age when the area became free of ice. Wilson (1981) states that Lake Agassiz drained from this area 8500 to 9000 years ago, based on radiocarbon dates from cores taken in the Lake Agassiz basin (Table 2, nos. 5, 6 and 7), the oldest being 8520 B.P.

This phase suggests that Lake Agassiz extended farther north at this level than was suggested by Elson (1967, Figure 10). The water level and ice position of Phase 3 correspond to Klassen's (1983) Phase 2 at 9000 B.P.

Phase 4

During Phase 4 (Figure 31), the ice front corresponded approximately to that shown by Prest (1970, Figure XII-15) for 9900 B.P. It correlates with the position during Klassen's (1983) Phase 3 at 8700 B.P. In the north, beaches were formed along the Cree Lake Moraine, which was at that time completely surrounded by the lake. The Saskatchewan Delta continued to build into Lake Agassiz.

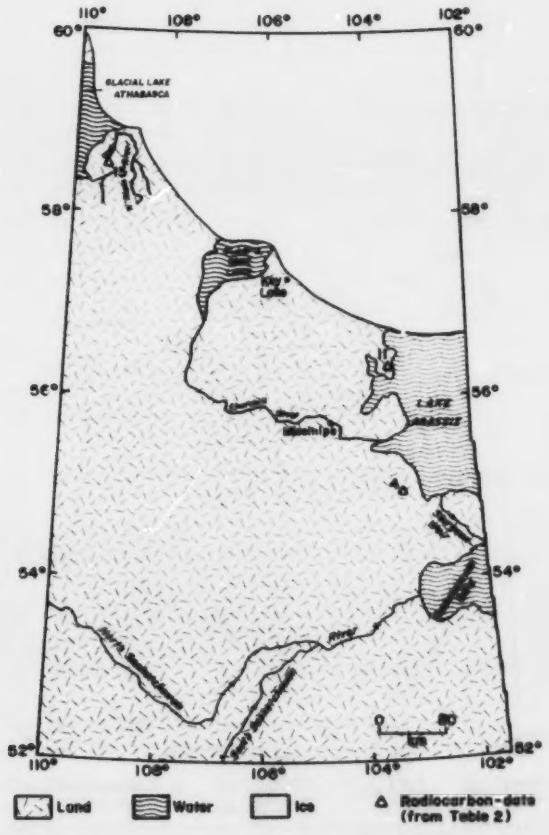


Figure 31. Deglaciation history (Phase 4), approximately 8700 years B.P.

The Sturgeon-weir River, in a canal-like channel, may have been operative at this time, carrying water south to an embayment of the lake (Figure 31). However, this would require separation of the northern part of the lake from the south by an ice dam or highland in Manitoba. Such a barrier is not evident (Klassen, 1983, Figure 6) and, therefore, the origin of the Sturgeon-weir outlet remains in doubt. Because this channel seems to be controlled by bedrock structure it may have formed prior to glaciation and was used as a drainage path prior to the last draining of Lake Agassiz. Alternatively, it may have acted as a subglacial channel carrying water beneath the ice.

During Phase 4, the ice stood at the northern end of Cree Lake (Figure 31). The water ponded against the ice front where the exposed land surface sloped toward the ice to form a basin, and Glacial Cree Lake was formed. Well-developed wave-cut terraces were eroded into the sides of drumlins up to an elevation of about 538 m. Drainage of the lake was south to the Mudjatik River, with the threshold of the drainageway at approximately 490 m. The difference in elevation of nearly 50 m between the strandlines and the threshold indicates that Glacial Cree Lake was bounded by ice to the north and was contained in a basin which was depressed due to isostatic subsidence. As rebound raised the basin, lake water spilled southward. Wave-cut terraces in drumlins surrounding the present lake mark the various episodes of rebound (Figure 11). Ice apparently blocked drainage to the east through the Wheeler River when the lake was at its highest levels. Smaller lakes, such as Wathaman, Davin, Costigan and Highrock Lakes, show slightly higher water levels due to blockage, by ice, of their northern drainage systems.

Northwest of the study area, a large glacial lake, Lake McConnell, occupied the lowland around the MacKenzie drainage system (Craig, 1965). The ice standing at the Cree Lake Moraine formed part of the eastern margin of this lake. Isostatic rebound and the resultant lowering of water levels eventually caused Lake McConnell to be separated into three smaller basins, around Great Bear Lake, Great Slave Lake and Lake Athabasca. The lake which surrounded present-day Lake Athabasca, herein referred to as Glacial Lake Athabasca, was separated from the other lakes by a bedrock sill which crosses the Slave River at Fort Smith (Craig, 1965). As the ice front retreated from the Cree Lake Moraine, this glacial lake invaded the newly exposed terrain (Figure 31). The retreat of the ice margin is marked by successive minor moraines. The lake levels are marked by strandlines, the highest being at about 305 m

(Figure 12). Radiocarbon dates (Table 2, nos. 4, 11, 15) indicate that the ice retrated to this position more than 6420 years ago.

Phase 5

During Phase 5 (Figure 32), the ice corresponded to the position shown by Prest (1970, Figure XII-15) for 9000 B.P. At that time it was a continuation of the ice-margin which crossed Southern Indian Lake in Manitoba (Manitoba Mineral Resources Division, 1981). Beaches are found in the northern part of the Lake Agassiz basin at an elevation of about 365 m. The Reindeer, Pagato and Kamatsi Spillways drained water from the northern part of the lake to the south (Figure 32). Once again, for these spillways to be operative, an ice dam or some blockage in Manitoba would have been necessary to separate the two parts of the lake. Such separation, however, has not been shown at present.

The ice retreat uncovered the McFarlane Spillway south of Davy Lake (Figure 32). Initially, the McFarlane Spillway north of Davy Lake was blocked

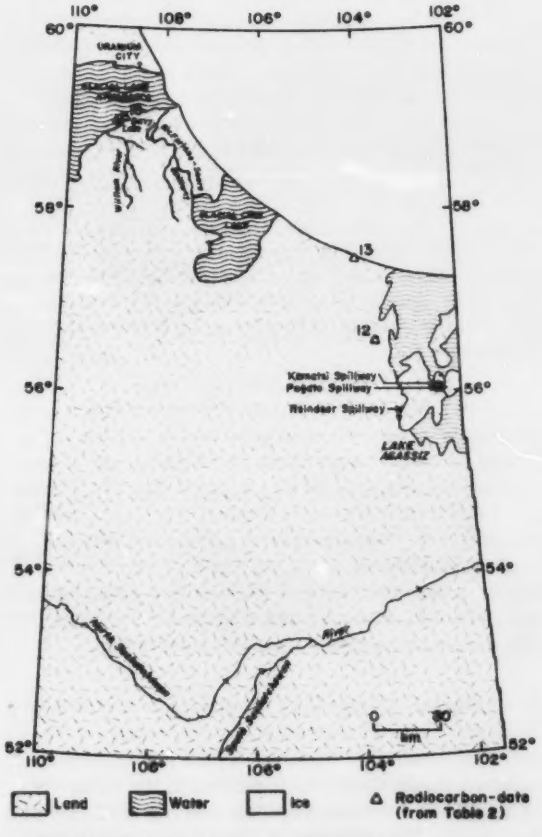


Figure 32. *Deglaciation history (Phase 5), approximately 8400 years B.P.*

by a lobe of ice which persisted in the basin. The former position of this lobe is marked by small sinuous end moraines found throughout the area south of Lake Athabasca. Glacial Cree Lake expanded northward and its highest strandlines here are marked by terraces cut into drumlins at about 520 m (Figure 11). The Mudjatik Spillway was abandoned as isostatic rebound raised the threshold and drainage was captured by the MacFarlane-Snare Spillway which drained north to Davy Lake. A small delta was formed where the river entered the lake. Since the McFarlane Spillway was blocked north of Davy Lake, water overflowed into a broad low-relief area west of the lake. This water eventually reacned the William Spillway and flowed north to Glacial Lake Athabasca, depositing sediment where it entered the lake.

As the ice front continued to retreat, successive spillways were opened west of and parallel to the MacFarlane Spillway north of Davy Lake and the William Spillway was abandoned. Eventually the portion of the MacFarlane Spillway north of Davy Lake became free of ice. Water drained from Glacial Cree Lake via Davy Lake to Glacial Lake Athabasca (Figure 32) and sediment was deposited in the lake basin. The level of Glacial Cree Lake was lowered as the retreating ice front uncovered successively lower drainage outlets to the northwest. The Otherside River acted as one of the main spillways and built a delta at an elevation of 305 m in Glacial Lake Athabasca near Richards Lake. The radiocarbon dates (Table 2, nos. 12, 13, 16) indicate that the area was ice free more than 7755 years ago and that Lake Agassiz retreated to the level shown in Figure 32 by at least 6910 years ago.

Phase 6

By the time the ice had retreated to the position shown in Figure 33, Glacial Lake Athabasca had expanded to the east along the Fond du Lac River and surrounded Black Lake and the north end of the Cree River. Strandlines, in particular the well-developed beaches and terraces south of Riou Lake, mark the highest shoreline at about 305 m (Figure 12).

In the northeastern part of the study area, drainage to the north was blocked, causing water to be ponded in the depressed basin which surrounded Wollaston Lake. This lake is here termed 'Glacial Wollaston Lake'. Strandlines at about 420 m south of Pow Bay on the west shore of Wollaston Lake (BS-2621) are the highest recorded. Water drained southeast through the Swan Spillway to Lake Agassiz which at this point was restricted to the area surrounding the Reindeer Lake Basin.

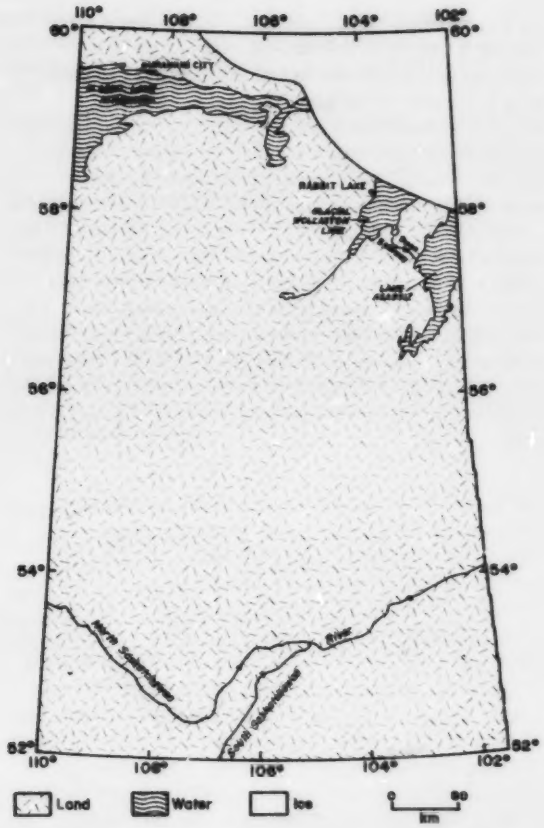


Figure 33. Deglaciation history (Phase 6), approximately 8200 years B.P.

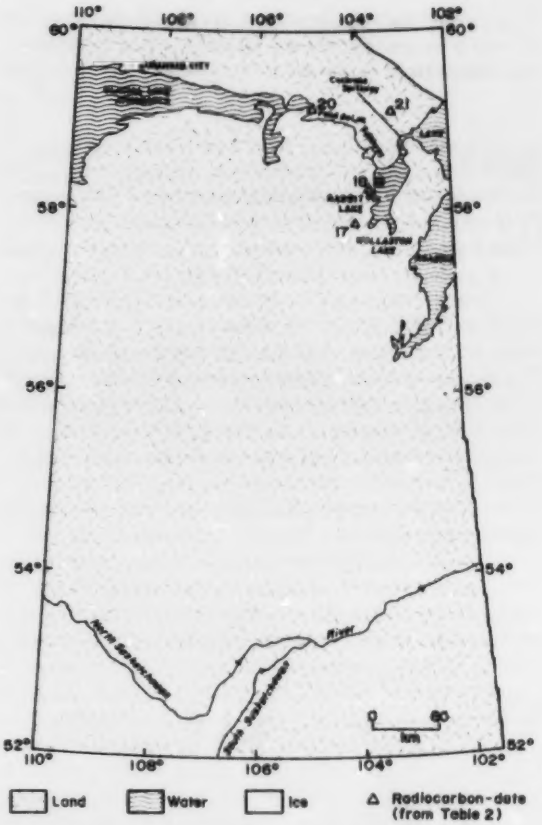


Figure 34. Deglaciation history (Phase 7), approximately 8000 years B.P.

Phase 7

During Phase 7 (Figure 34), the ice position corresponded to that depicted by Prest (1970, Figure XII-15) for 8900 B.P. This position also correlated approximately with margins in Manitoba according to Klassen (1983) and Dredge (1983). There is little evidence of Lake Agassiz in the northern part of the Reindeer Lake basin and farther north. Beaches are reported by Stockwell (1929) inland along the Reindeer Lake shore, the highest being at an elevation of about 348 m. These beaches are assumed to be remnants of Lake Agassiz. The outline of the lake as shown in Figure 34 is drawn to correspond with the lake in Manitoba, as reported by Dredge (1983). The rebound curve used by Klassen (1983) for his Phase 4 is applied here and the lake outline is projected south along Reindeer Lake (Figure 34).

When the ice had retreated to the position shown in Figure 34, Lake Agassiz inundated the Cochrane River but the Fond du Lac Spillway was opened. Glacial Wollaston Lake drained north to Lake Agassiz and northwest to Glacial Lake Athabasca. A radiocarbon date (Table 2, no. 18) on a sample taken from the base of peat deposits in Rabbit Lake just west of Wollaston Lake indicates that the area was ice free and that Glacial Wollaston Lake drained at least 8335 years ago.

The Fond du Lac River below 305 m near Black Lake meanders in a broad sand plain which fills the valley. These sediments were likely deposited when Glacial Wollaston Lake drained and suggest that the Glacial Lake Athabasca shoreline around Black Lake was at about 305 m. This elevation is coincident with the highest strandlines along the Fond du Lac River and around Lake Athabasca. A radiocarbon date (Table 2, no. 20) south of Black Lake (Figure 34) indicates that this area was ice free at least 6855 years ago.

In all phases, Glacial Lake Athabasca is shown with a consistent shoreline defined approximately by the 305 m contour line. However, as the ice retreated, isostatic readjustment took place and the waters of Glacial Lake Athabasca spilled over the sill south of Fort Smith. This resulted in the successively lower strandlines which surround Lake Athabasca

(Figure 12). In order for the highest strandline to be consistent over the length of the lake, the rate of isostatic rebound must have been almost directly proportional to the rate of ice retreat and lake invasion in the basin. Since these rates are difficult to estimate, no attempt has been made to portray the true areal extent of Glacial Lake Athabasca at any one point in time.

The radiocarbon date at Phelps Lake (Table 2, no. 21) indicates that the area was free of ice at least 5850 years ago. This phase correlates with Klassen's (1983) Phase 4 at 8000 B.P.

Postglacial History

The study area was free of ice at least 8000 years ago according to radiocarbon dates (Table 2). Drainage of water continued and glacial lake levels lowered. Lake Agassiz had nearly abandoned the area as much as 8000 years ago (Figure 34). Surficial sediments were exposed, soon became dry and were then affected by strong winds. According to David (1981a), strong adiabatic winds blew from a southeasterly direction along the front of the ice mass as it retreated from the area. These winds transported sand and silt, the sand forming elongate parabolic dunes while the silt-sized material was laid down as a blanket of loess beyond the dunes. Vegetation of the active eolian areas was slow until the prevailing wind direction changed to the southwest. A rapid invasion of plants then fixed the dunes in a form which has been only slightly altered by modern northwesterly winds.

South of Lake Athabasca, the lacustrine and deltaic sediments deposited mainly by the William and MacFarlane Rivers dried out and northwesterly winds activated the fine material to form the presently active sand areas with their various dune forms (David, 1977a, 1977b, 1981b).

The history of vegetation is provided by the study of pollen and spores in cores taken from muskeg or shallow lakes. Mott (1967, 1969, 1973) and more recently Wilson (1981) studied the palynology of the eastern part of the area. The accumulation of pollen began at about the same time as the ice retreated. A unique tundra-like vegetation invaded the area, suggesting a climate, dominated by cold polar air for most of the year, that inhibited tree growth. This was followed by a period during which large open areas existed, with groves of spruce trees growing in favourable locations. This is similar to the present vegetation pattern in a transition zone near the tree line, where climatic conditions are similar to those of the boreal forest. According to Mott (1973), pine entered the area about 6000 years ago. The present forests of the area are described by Rowe (1959). Wetlands developed in the low-lying areas.

Permafrost formed under the cold conditions which persisted in front of the ice mass as it retreated. Permafrost is now found only in low-lying peat bogs where the peat insulates the permafrost from the prevailing summer temperatures. These are too high to allow the development or preservation of permafrost in non-insulated localities. The periglacial conditions which existed in the area just after the ice retreat also gave rise to congeliturbation features in the active layer (Plate 56).

Soil development began shortly after ice retreat. The formation of soil is related primarily to parent material, but also to topography, drainage, time, climatic factors, vegetation and soil micro-organisms.

Modern effects of lake ice are found in the form of lake ramparts. Beaches, berms, deltas and other shoreline features are presently forming, especially along the south shore of Lake Athabasca.

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Appendix A: Soils of the Saskatchewan Precambrian Shield

by D.F. Acton[1] and G.A. Padbury[1]

The soils within the Precambrian Shield region contrast sharply with those of the Prairie region of southern Saskatchewan. Most prairie soils are formed in a relatively warm environment under grassland vegetation and feature a dark surface horizon high in nutrients. In contrast, most soils on the shield are formed in a relatively cool environment under forest vegetation, and are characterized by a greyish surface horizon overlain by a shallow layer of organic materials or forest litter. Another difference is that most shield soils are nearly devoid of clay, reflecting a marked contrast in the nature of the surficial geological deposits on the Shield compared to the Prairie Region.

Although most soils on the Shield possess the general charcteristics described above, variations in the degree of weathering and in processes involved in soil formation give rise to many different types of soils.

Seven of the nine major soil orders[2] found in Canada occur in the study area. Brunisolic, Luvisolic and Podzolic soils dominate the well-drained upland areas, while Gleysolic and Organic soils dominate the poorly and very poorly drained lowland areas. Regosolic soils occur on floodplains and in unstable areas such as dunes and slumps. Cryosolic soils (i.e. soils containing permafrost) occur mainly in organic terrain. Bedrock that is overlain by less than 10 cm of unconsolidated material is considered non-soil.

Brunisolic Soils

Brunisolic soils are the commonest soils in the study area and occur mainly on glaciofluvial and glacial till deposits and, to a minor extent, on glaciolacustrine deposits. In general, they develop on well-drained surficial deposits where the clay fraction (<2 mμ) is less than 5 percent and the silt fraction (2 to 50 mμ) less than 10 percent.

Most Brunisolic soils on the shield have undergone podzolization, as evidenced by their well-developed greyish Ae horizons and reddish B horizons. They do not, however, have sufficient pyrophosphate-extractable Fe and Al in the B horizon to meet the criteria specified for Podzolic soils. They are classified, according to their acidity, as either Dystric Brunisols or Eutric Brunisols, with the more acidic Dystric Brunisols being more common.

In general, Brunisolic soils are characterized by a surface organic layer (L-H horizon) underlain by Ae and Bm horizons (Plate 75). In arid locations, the L-H horizon is often thin (1 to 2 cm) and composed mainly of partially decomposed needles, lichens and ericaceous shrubs. In moister areas, the L-H horizon is generally thicker (5 to 10 cm) and derived largely from feather-mosses under coniferous forests or leaves, stems and twigs under deciduous forests. The Ae horizon is grey, structureless and ranges in thickness from 2 to more than 30 cm. In some instances, the lower boundary of the Ae horizon is very irregular, with narrow pockets extending up to 30 cm into the underlying B horizon. The Bm horizon is usually structureless, and grades in colour from reddish or reddish-brown in its upper part to yellowish-brown or pinkish in its lower part. The lower part of the horizon is often difficult to distinguish from the parent material, or unaltered surficial deposit. The Bm horizon ranges in thickness from 15 to more than 100 cm. In general, the solum (that part of the surficial deposit which has been modified by soil-forming processes) ranges in thickness from 20 to more than 100 cm, with profiles on the middle and lower portions of slopes having thicker horizons than those on upper slope portions.

In most glaciofluvial deposits, the Ae and Bm horizons are friable and have a single grain structure; in some glacial tills, they are hard, very compact and massive.

The analysis of a Brunisolic profile from the upper slope of a sandy ridge near the Haultain River is given in Table 3. Note the low pyrophosphate-extractable Fe and Al values, indicating less intense podzolization than in Podzolic soils. This is due to the comparatively dry soil environment of Brunisolic soils, as well as to subtle differences in the composition of the parent materials.

Podzolic Soils

Podzolic soils, which occur sporadically throughout the study area, are generally found on moist, moderately well to imperfectly drained lower slopes and level areas surrounding poorly drained depressions. They are most frequently associated with glacial till and glaciofluvial deposits containing less than 5 percent clay and 20 to 50 percent silt.

Podzolic soils in the study area are similar in appearance to the Brunisolic soils, being characterized by a surficial organic L-H horizon underlain by a greyish A horizon and a reddish B horizon (Plate 76). Being the product of more intense podzolization, as evidenced by the higher pyrophosphate-extractable Fe and Al values in the B horizon (Table 3), they generally exhibit more distinct, highly developed horizons than Brunisolic

[1]Saskatchewan Institute of Pedology, University of Saskatchewan, Saskatoon, Saskatchewan.

[2]The Canadian System of Soil Classification, Research Branch, Canada Department of Agriculture, 1978.

Table 3. Chemical and Physical Characteristics of Representative Brunisolic, Podzolic and Luvisolic Soils

Horizon	Depth (cm)	Colour (moist)	pH	E.C. (mmhos/cm @ 25°C)	Total N (%)	Organic C (%)	Dithionate Fe (%)	Dithionate Al (%)	Pyrophosphate Fe (%)	Pyrophosphate Al (%)	Cation Exch. Capacity	Particle Size Distribution (%) Sand (2000-50 μm)	Silt (50-2 μm)	Clay (<2 μm)	Fine Clay (<0.2 μm)
Orthic Eutric Brunisol:															
Aeh	0 - 8	10YR5/1	5.2	0.2	0.1	1.37	0.14	0.06	0.06	0.05	4.6	95.1	4.3	0.6	-
Bm	8 - 15	10YR6/6	5.5	0.1	0.0	0.22	0.21	0.13	0.05	0.02	1.6	96.6	2.4	0.8	-
BC	15 - 51	10YR7/4	5.8	0.1	0.0	0.06	0.16	0.07	0.01	0.03	0.8	97.1	2.9	0	0
C	51 - 66	10YR7/3	5.7	0.1							0.7	94.8	5.2	0.2	0
Orthic Humo-Ferric Podzol:															
LH	10 - 0	10YR2.5/1	3.7	0.6	1.2	1.78	0.10	0.04	0.01	0.01	29.2				
Ae	0 - 15	10YR6/2	3.9	0.2	0.0	0.26	0.71	0.45	0.08	0.50	1.7	86.2	12.9	0.9	0
Bf	15 - 33	10YR5/4	4.8	0.1	0.1	1.33	0.71	0.45	0.05	0.16	7.6	82.6	13.5	3.9	1.3
Bm	33 - 46	10YR5/6	5.3	0.1	0.0	0.29					3.0	86.7	11.6	1.7	0.6
C	46 - 56	10YR5.5/4	5.0	0.2							1.6	81.6	17.6	0.8	0
IIC	56 - 66	10YR6.5/3.5	4.5	0.2							4.0	23.2	70.4	6.4	0.6
Orthic Grey Luvisol:															
LH	10 - 10		5.0	0.2		1.3									
Ae	0 - 10	10YR7/2	5.2	0.3	0.11	0.5	0.7	0.1	0.2	0.20	25.4	6	21	73	17
AB	10 - 30	10YR5/2	5.5	0.3	0.09	0.4	0.5	0.1	0.1	0.10	26.2	3	17	80	24
Bt1	30 - 50	10YR5/2	6.0	0.3	0.05	0.3	0.6	0.1	0.1	1.07	31.8	1	8	92	40
Bt2	50 - 85	10YR5/2	6.8	0.3	0.04	0.3					27.7	1	9	91	32
Bt3	85 - 105	10YR5/2	6.9	0.3	0.04	0.2					27.3	1	10	90	34
Bt4	105 - 135	2.5Y5/2	6.9	0.3	0.05						27.6	1	11	89	36
C1	135 - 155	2.5Y5/2	6.7	0.3							27.5	1	14	85	30
C2	155 - 160	2.5Y5/2		0.3							-	1	19	80	28

soils. The bulk of Podzolic soils in the study area are classified at the Great Group level as Humo-Ferric Podzols.

Luvisolic Soils

Luvisolic soils, which are widespread in the area formerly covered by Lake Agassiz, are associated almost exclusively with well-drained glaciolacustrine and glacial till deposits in which the clay fraction (<2 mμ) exceeds 5 percent. They are formed largely as a result of lessivage, a soil-forming process in which clay and, in some instances, fine silt are washed in suspension from the A to the B horizon of a soil. The B horizon is thus enriched in clay compared to the A and/or C horizons.

Luvisolic soils in the study area are characterized by a surficial organic L-H horizon underlain by a grey Ae horizon and a brown to dark brown Bt horizon (Plate 77). The L-H horizon varies from 5 to 15 cm in thickness, and is composed mainly of partially decomposed leaves, stems, twigs and in some cases feather-mosses, particularly under dense stands of conifers. The Ae horizon ranges in thickness from 5 to more than 30 cm, the greater thicknesses generally occurring in the coarser textured deposits. The Ae horizon in fine-textured sediments is somewhat hard and has a weak subangular blocky structure; in coarser textured sediments, it is more friable and exhibits a platy structure. In most Luvisolic profiles, the Ae horizon is underlain by a transitional AB horizon, which formed as a result of partial removal of clay from the upper part of the Bt horizon. This removal of clay leaves a sandy coating on the surface of the soil aggregates, giving them a greyish colour. The AB horizon ranges from 10 to 30 cm in thickness, is hard and exhibits a subangular blocky structure. The Bt horizon is dark brown to greyish-brown, hard and has a subangular blocky structure, which in fine-textured deposits crushes easily into fine, subangular, blocky or nutty aggregates.

Luvisolic soils in the study area are classified at the Great Group level as Gray Luvisols, and at the Subgroup level as either Orthic Gray Luvisols (in well-drained locations) or Gleyed Gray Luvisols (in imperfectly drained locations). The analysis of an Orthic Gray Luvisol profile developed on glaciolacustrine deposits near Manawan Lake is given in Table 3. Note the difference in the clay (<2 mμ fraction) contents of the Bt horizons compared to the Ae and C horizons.

Gleysolic Soils

Gleysolic soils commonly occur in poorly drained depressional and level areas. They are generally saturated with water in the spring and under reducing conditions throughout most of the year. Gleysolic soils are commonly associated with a periodic or permanently high water table and typically support hydrophytic vegetation.

Most Gleysolic soils in the study area have a shallow (less than 40 cm) layer of peat at the surface. The underlying mineral soil is generally a dull bluish- to greenish-grey colour, although bluish-green or reddish streaks and splotches are common, particularly in coarser textured deposits. In the landscape, the Gleysolic soils are typically found below the well-drained soils but above the very poorly drained areas which commonly contain Organic soils.

Regosolic Soils

Regosolic soils represent weakly developed, immature soils which consist largely of surficial geologic deposits unaltered by soil-forming processes. This is due either to the immaturity, instability or nature of the material, or to a dry cold climate. In the study area, most Regosolic soils are associated with surficial materials that are either unstable (e.g. sand dunes or slump deposits) or very youthful (e.g. floodplains).

Organic Soils

Soils of the Organic Order contain 17 percent or more organic carbon by weight and differ from the other orders in having been derived mainly from organic materials. Organic terrain occupies extensive tracts in the study area, but is confined largely to very poorly drained, level to very gently sloping or depressional areas in which a water-saturated environment is maintained throughout much of the growing season.

Organic deposits, or peat, result from the accumulation of plant remains and, to a minor extent, animal residues. In peat formation, the main factor which enables the organic residues to accumulate is excess water, which causes an oxygen deficiency at the surface, thereby reducing the rate of decomposition. Such a situation occurs either when precipitation exceeds evaporation for extended periods, or when the local topography impedes drainage. The development of peat is also promoted by high acidity and low nutrient levels, both of which reduce microbial activity and hence slow the rate of decomposition.

Organic terrain can be divided, on the basis of the origin of the organic material, into bogs and fens. Bogs consist largely of sphagnum and forest peat. Sphagnum peat, as the name implies, is derived mainly from sphagnum moss and, to a lesser extent, from feathermosses, ericaceous shrubs and the

debris of trees such as larch and black spruce. It is usually light yellowish-brown to very pale brown in colour and relatively undecomposed, with the sphagnum plants remaining more or less intact. Forest peat is derived largely from feathermosses, ericaceous shrubs and woody fragments derived from the forest cover. It is usually moderately to well decomposed and very dark brown to dark reddish-brown in colour. Fens consist of peat derived mainly from sedges and, to a lesser extent, from grasses, shrubs and aquatic species. The peat is generally very dark brown in colour and has a matted or layered structure. It is usually moderately decomposed, although the degree of decomposition increases slightly from the surface downward in most fens.

In general, peat deposits which occupy large, low-lying areas are deep and relatively uniform in composition. However, those formed in local hollows or in stream channels are subject to many different environmental conditions due to fluctuating water tables and usually exhibit a more varied and complex stratification.

Organic soils are classified at the Great Group and Subgroup levels on the basis of degree of decomposition and depth of the deposit. In the study area, Organic soils are classified at the Great Group level as Fibrisols, Mesisols and Humisols, representing increasing degrees of decomposition.

Cryosolic Soils

Cryosolic soils have permafrost within 1 m of the surface, or within 2 m if they have been strongly cryoturbated. Cryosolic soils in the study area are generally restricted to organic deposits and have permafrost within 1 m of the surface throughout the year. They are most commonly found on *palsen* (domed bog landforms which consist of mounds or ridges of organic material several tens of metres in width and raised 1 to 2 m above the surrounding terrain). Cryosolic soils generally support moderate to dense stands of black spruce in which many of the trees are tilted due to movement of the soil, a result of frost heaving or the subsequent melting of the permafrost.

Acknowledgments

The authors gratefully acknowledge the opportunity provided by the study directors to investigate the soils of this region. We also acknowledge the contributions of R.J. St. Arnaud and A.K. Ballantyne of the Saskatchewan Institute of Pedology for advice in the field and the laboratory analysis, respectively.

Appendix B: Seismic Investigation of Pleistocene Features in the Vicinity of Stony Rapids

by A.T. Schneider[1]

Several seismic refraction studies were carried out during the summer of 1978 in the vicinity of Stony Rapids to supplement information from the mapping program in the absence of overburden drilling. An esker intersecting the road from Stony Rapids to Black Lake was studied to determine its thickness, composition and any possible relation to bedrock relief. The total thickness of the Quaternary deposits was determined at several locations along the same road (Figure 35). A drumlin at Hozempa Lake, southwest of Stony Rapids, was subjected to a thickness and composition study similar to that carried out on the esker.

An explanation of the seismic refraction method lies beyond the scope of this report. Excellent summaries of the underlying theory and the basic procedure are given by Grant and West (1965), Parasnis (1962) and Sharma (1976).

The refraction technique provides differing travel times for compressional elastic waves in layers of contrasting physical properties, and calculations lead to the position or depth of the corresponding interfaces. However, as these numbers do not directly imply a geological description for a particular layer, interpretation of the data requires significant geological input, considerable previous experience and, preferably, information on the physical properties of near-surface materials in the area of interest.

No such information was available for the Stony Rapids area, so velocity interpretations had to rely on general experience. Table 4 summarizes the most likely relationships for an environment in which reworked sand tends to dominate.

Table 4. Typical wave velocities for materials in the Stony Rapids area.

Compressional Wave Velocity (m/s)	*Geological Designation*
300-600	Very loose material with little cohesion; mostly sand, with some gravel or weathering layer
1400-1900	Wet sand and gravel below water table; averages approx. 1600 m/s but may be as low as 1300 m/s and as high as 2200 m/s
2000-2400	Wet compacted glacial till with varying clay and/or sand content
3200-4500	Bedrock (Athabasca Group sandstone)

The refraction travel times were measured using a 12-channel RS-4 seismograph connected to cables whose geophone take-out spacing was 10# or 15 m. Three to five shots were generally fired for each spread, supported whenever possible by offset shots 50 m from either end of the spread. The size of the explosive charges was approximately 50 g and nowhere exceeded the 100 g limit.

Esker on the Stony Rapids — Black Lake Road

Figure 36 shows the arrangement of the six seismic refraction lines; lines A, F, D and E were laid out more

[1]Formerly of Saskatchewan Research Council, Saskatoon, Saskatchewan.

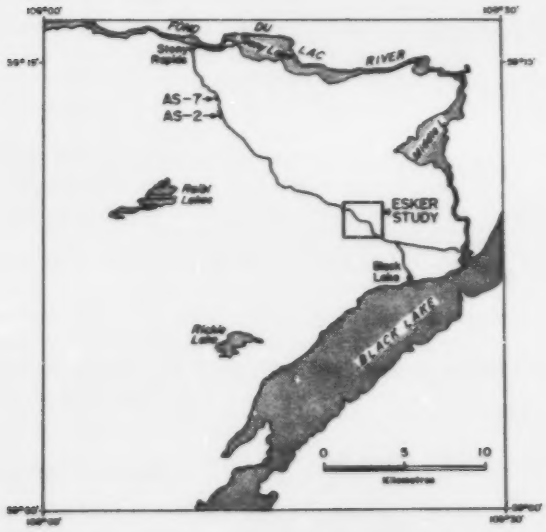

Figure 35. Locations of esker study and sites AS-2 and AS-7 (NTS 74 P-4)

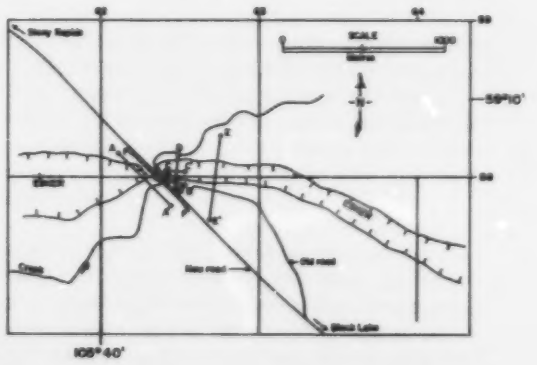

Figure 36. Location of seismic profiles for the esker study

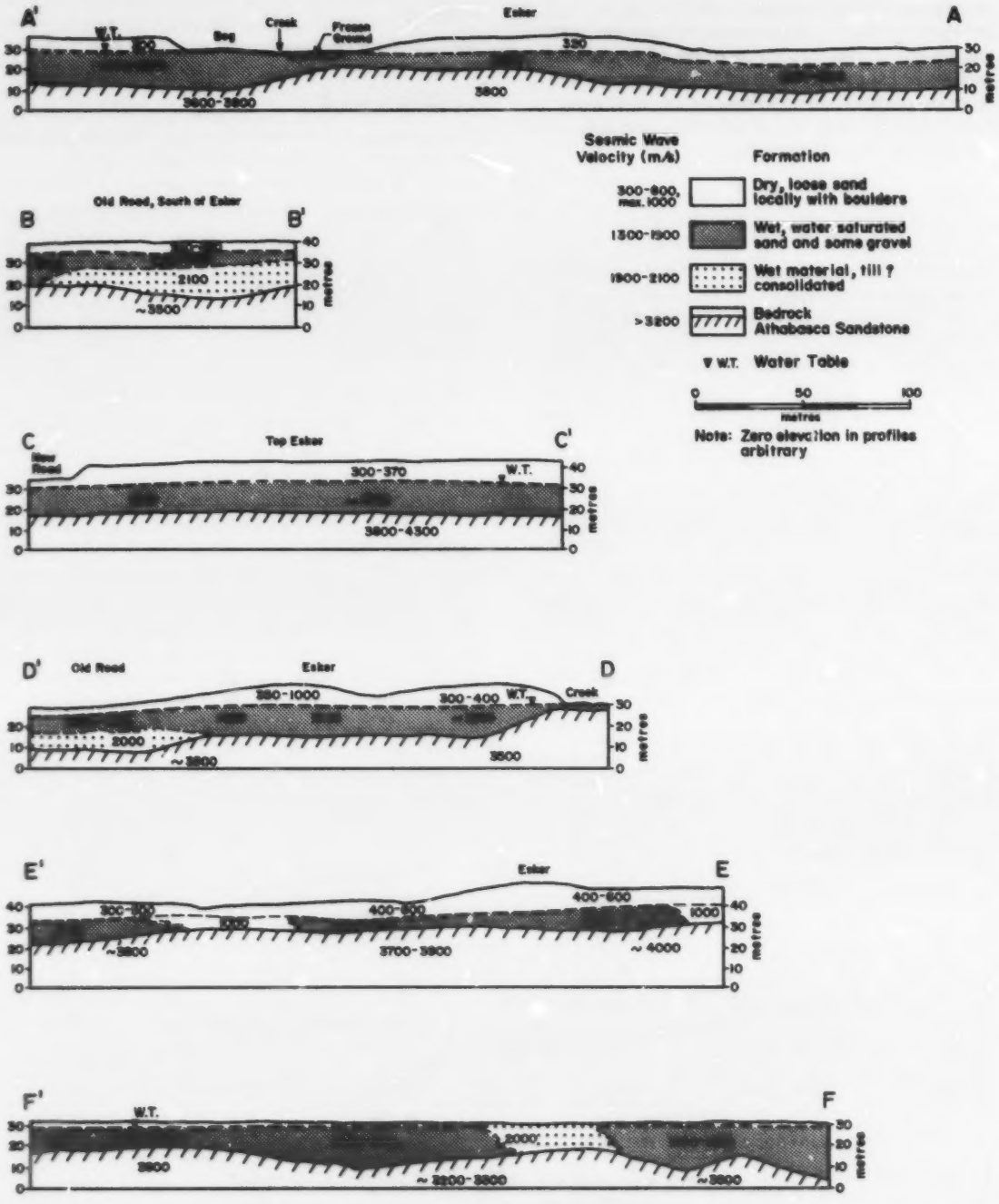

Figure 37. Seismic profiles of esker

or less perpendicular to the esker, while B and C are nearly parallel to its axis. North of the creek, the shotholes could not be drilled deeper than 0.8 m due to the presence of permanently frozen ground. In order to obtain reasonable resolution, the seismometers were placed at 10 m intervals[1] with shotpoints normally every 30 or 40 m. The resulting profiles are shown in Figure 37. The area marked 'bog' on profile A-A' no longer exists; meltwater runoff during the spring of 1979 filled the area with sand eroded from the roadbed.

The low velocity layer (300 to 1000 m/s), located at the top of all profiles, generally consists of dry sand with or without gravel. The higher values encountered within the esker (profile D-D') indicate the presence of boulders. The groundwater table within this sandy, poorly consolidated material is usually marked by a significant velocity contrast. Below this interface, seismic velocities of 1400 to 2000 m/s were observed, the average for saturated sand being 1600 m/s. Some minor variations toward slower velocities were encountered in profiles A-A' and E-E'. The two layers, therefore, are believed to consist of the same esker-type material, the only difference being that the lower layer is saturated with water.

In sections D-D' and B-B', a third layer was found between the esker material and bedrock. Its higher seismic velocities of 2000 m/s and more are probably due to its greater degree of consolidation (e.g. by overlying ice). Thus, it is likely older than the esker and could be a lodgement till.

[1]except on the northern part of line E-E', where a spacing of 15 m was used.

The surface of the underlying sandstone appears to be undulating with a vertical relief of 10 to 20 m. The profiles indicate that the esker is not related to any features on the bedrock surface, at least in the area examined.

Location AS-2

The location of this site is shown on Figure 35, while results of this 200 m seismic line are given in Figure 38. Although the seismic velocity distribution is quite similar to that from the esker described above, the shallow interface separating the 300 m/s layer from the underlying higher velocity material (1500 to 2000 m/s) is probably caused by weathering of clay-rich till rather than by the presence of a water table that would not likely be defined clearly in compact clay or silt.

The creek coincides with a depression in the bedrock. Evidently the present drainage follows an older pattern that is in the process of being unearthed.

Location AS-7

The location of this site is shown on Figure 35; no profile diagram is provided due to the very thin nature of the drift. At the northwestern end of this 110 m line, the shothole drill encountered no more than 0.8 to 1 m of material overlying the bedrock. At the southeastern end of the line, depth calculations indicate no more than 1.6 m of overburden. An additional seismic line, about 1 km further to the southeast, encountered bedrock at the same shallow depth.

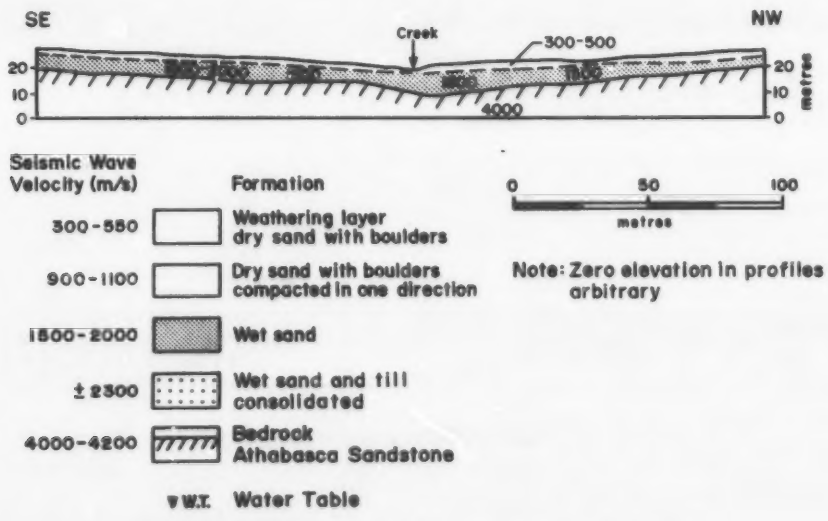

Figure 38. Seismic profile at site AS-2, Stony Rapids — Black Lake road

Drumlin in Hozempa Lake

Three seismic lines were shot in order to investigate the total thickness, internal composition and possible relation to bedrock features of a drumlin on the east shore of Hozempa Lake (NTS 74 J-15; Figure 39). Lines G-G' and H-H' were run parallel to the long axis of the drumlin, along its crest and base respectively (Figure 39). Line I-I', run across the drumlin, provided travel times and wave velocities, but did not yield depth information because of its limited length and the rugged topography of the drumlin.

The resulting profiles are shown in Figure 40. Water-saturated material with consistent wave velocities of approximately 2300 m/sec occupies a 15 m layer between bedrock and the water table (which in this area corresponds to the surrounding lake level). The relatively high velocity of this layer suggests that it consists of sandy till compressed by ice of the last glaciation. In the dry, upper position (±15 m) of the drumlin, the seismic wave velocities depend on the direction of wave propagation: velocities of 500 to 550 m/s are observed for waves travelling at right angles to the drumlin; those travelling parallel to the long axis of the drumlin have velocities of about 1000 m/s. This velocity contrast could be due to longitudinal compression of the sediment in the drumlin during glaciation. Geophysical evidence suggests that the ice sheet carved the drumlins out of an existing till layer up to 30 m in thickness.

In order to determine the nature of the bedrock surface in this area, a north-south seismic line was shot on the beach of the lake, about 200 m from the drumlin (line J-J', Figure 39). The overburden in this locality was approximately 3 to 4 m thick. Indications are that the top of the sandstone is uneven with variations near 10 m.

Summary

1) The refraction method clearly delineates such major interfaces as the water table and the bedrock surface.

2) The study was capable of distinguishing the following types of overburden: loose esker-like deposits, both dry and water saturated; more compact till-like material probably compressed by ice; anisotropic material in a drumlin, reflecting a certain stress pattern during the movement of the glaciers.

3) The Stony Rapids - Black Lake esker is not controlled by any features on the bedrock surface.

4) An old buried drainage system is being reactivated at location AS-2.

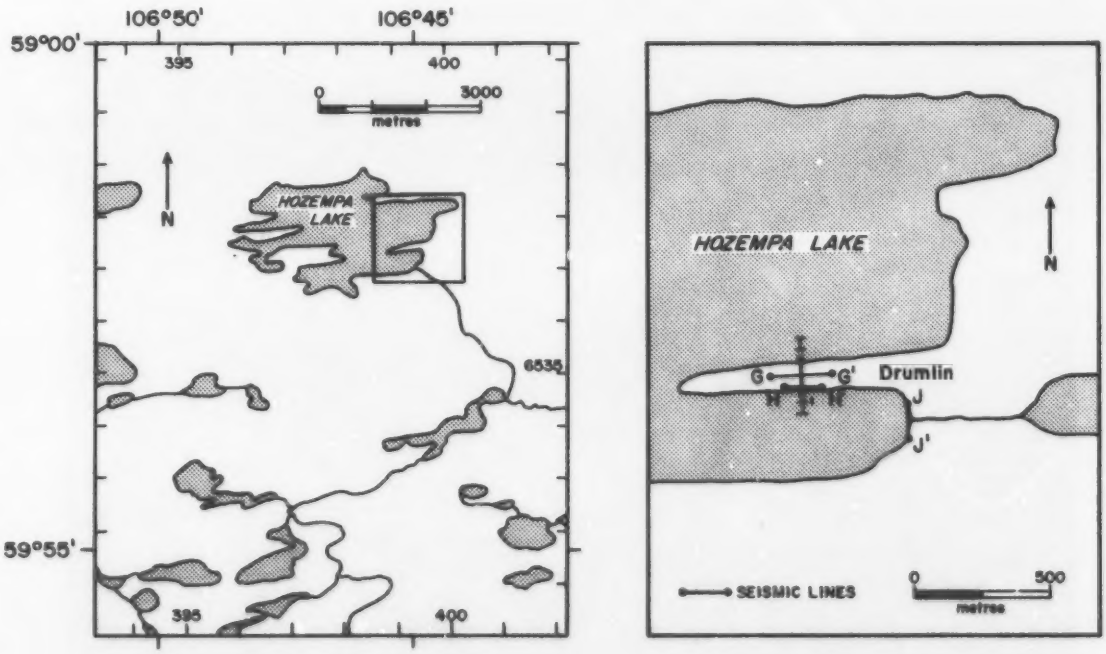

Figure 39. Location of drumlin study, Hozempa Lake (NTS 74 J-15)

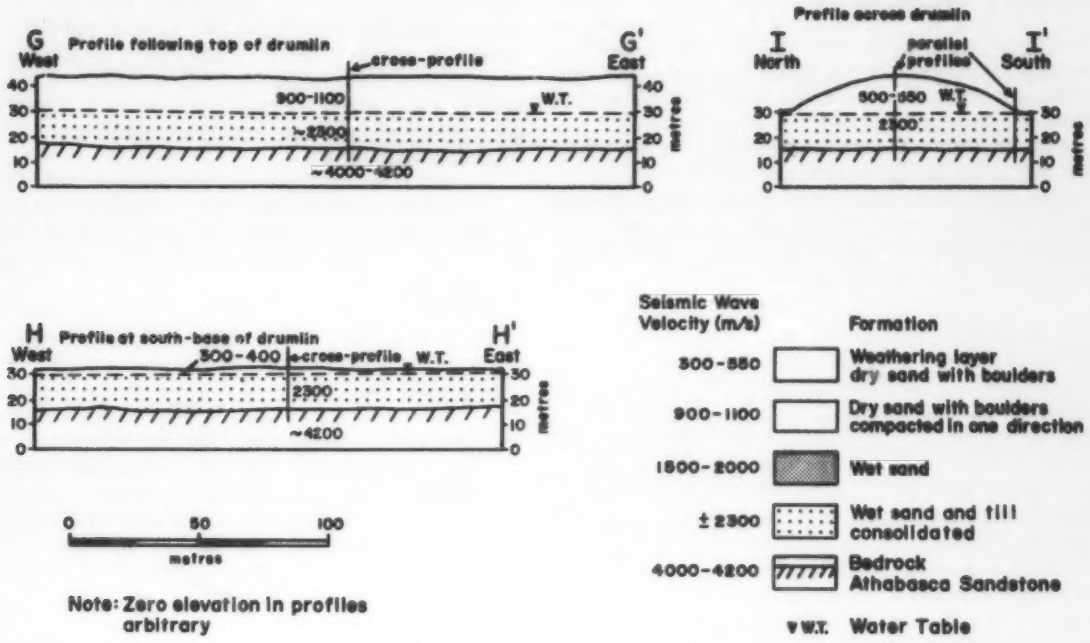

Figure 40. Seismic profiles of drumlin, Hozempa Lake

Recommendation

If drilling is not possible, subsurface studies of Quaternary deposits on the Precambrian Shield should be conducted through a combination of electric resistivity and seismic refraction so that grain-size estimates can be made. Identification of sediment types would then become much more reliable.

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Plates

Plate 1. *Truck-mounted power auger used to obtain samples of the upper 35 m of unconsolidated material*

Plate 2. *Oblique aerial photograph showing surface expression in the Kazan Upland south of Foster Lakes*

Plate 3. *Striations and grooves oriented parallel to bedding in Athabasca Group sandstone near Weitzel Lake (NTS 74 G-15). A glacial erratic rests on the bedrock in the lower right corner of the photo*

Plate 4. *Box-like gullies or trenches formed by runoff in silt where vegetation had been removed, Hwy. 105 near Brabant Lake (NTS 64 D-4)*

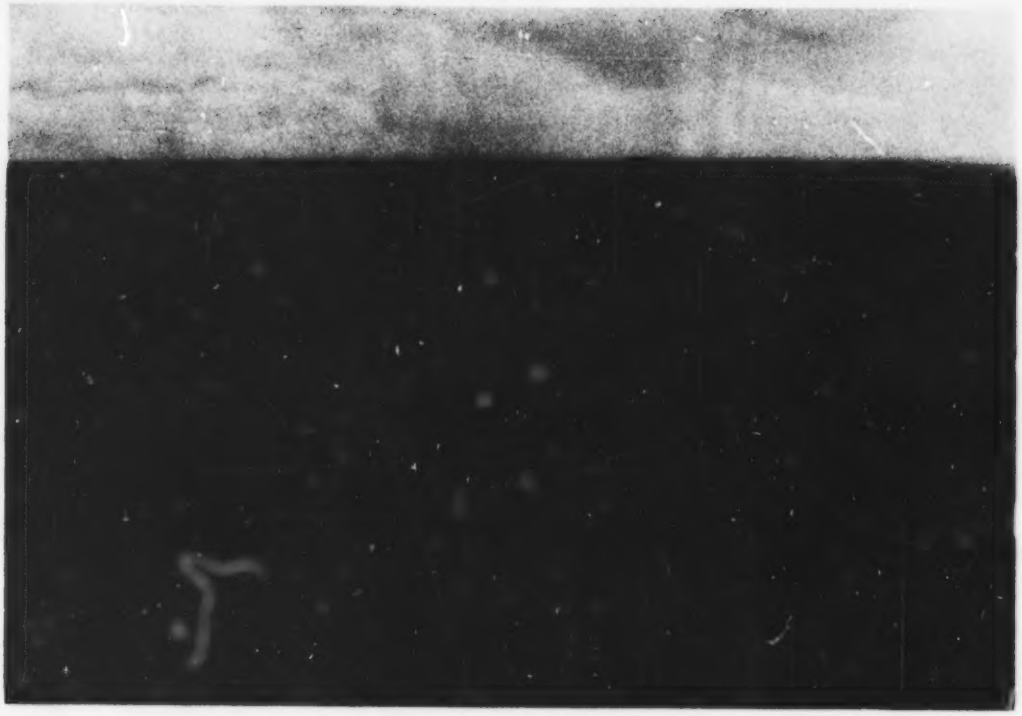

Plate 5. *Hill slope gullies cut into the steep sides of a drumlin by runoff. The distinct, narrow, V-shaped troughs indicate the presence of compact, fine-grained sediment. This drumlin near Keefe Lake (NTS 74 H-10) is composed of very sandy material eroded from the underlying sandstone of the Athabasca Group*

Plate 6. *Cree Lake Moraine. South of Paul Lake (NTS 74 A-2), the moraine occurs as a single, narrow ridge which probably formed in a channel between two ice masses*

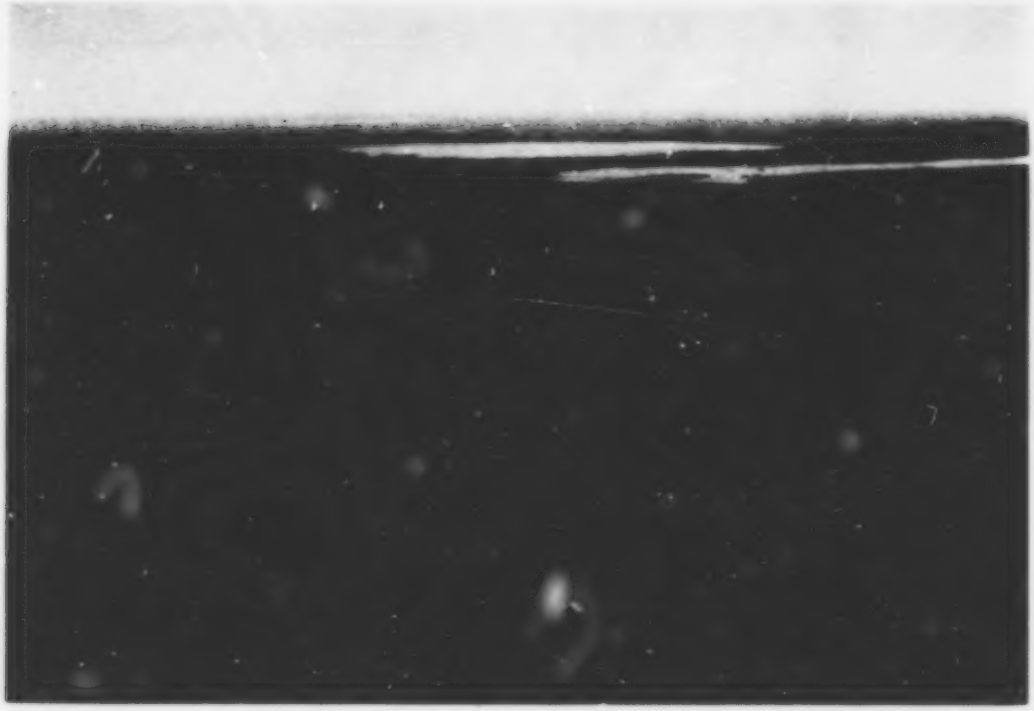

Plate 7. Cree Lake Moraine. South of Lloyd Lake (NTS 74 F-6), the moraine consists of a broad, hummocky band of multiple ridges dotted with kettles.

Plate 8. Cree Lake Moraine (vertical aerial photograph). Near Forrest Lake (NTS 74 F-11), the moraine consists of small sinuous ridges of low relief.

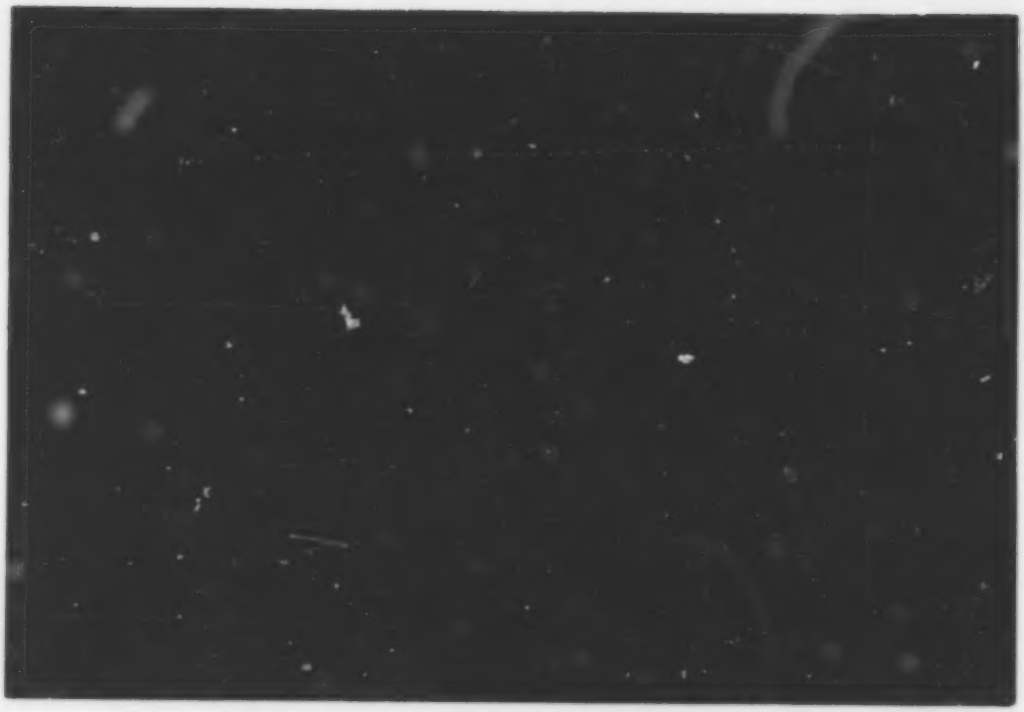

Plate 9. *End moraine forming the south shore of McGunigal Lake in the McTavish Lake area (NTS 73 P-14)*

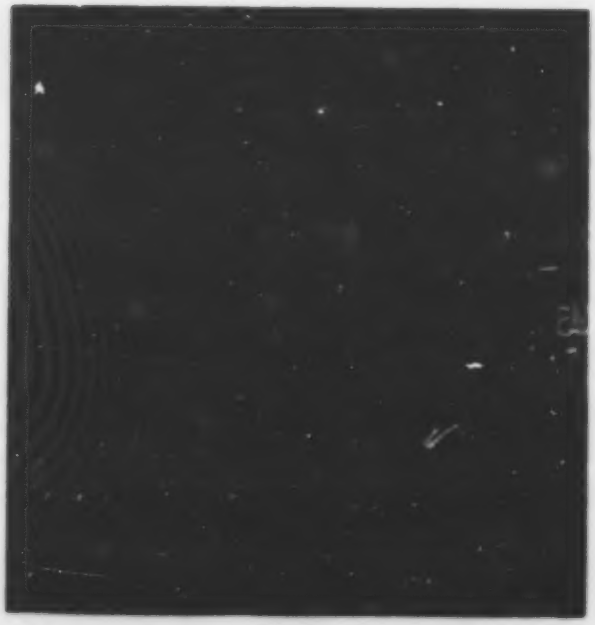

Plate 10. *Vertical aerial photograph of minor moraine ridges showing a symmetrical pattern, near Forrest Lake (NTS 74 F-11)*

Plate 11. *Oblique aerial photograph of the minor moraines in Plate 10*

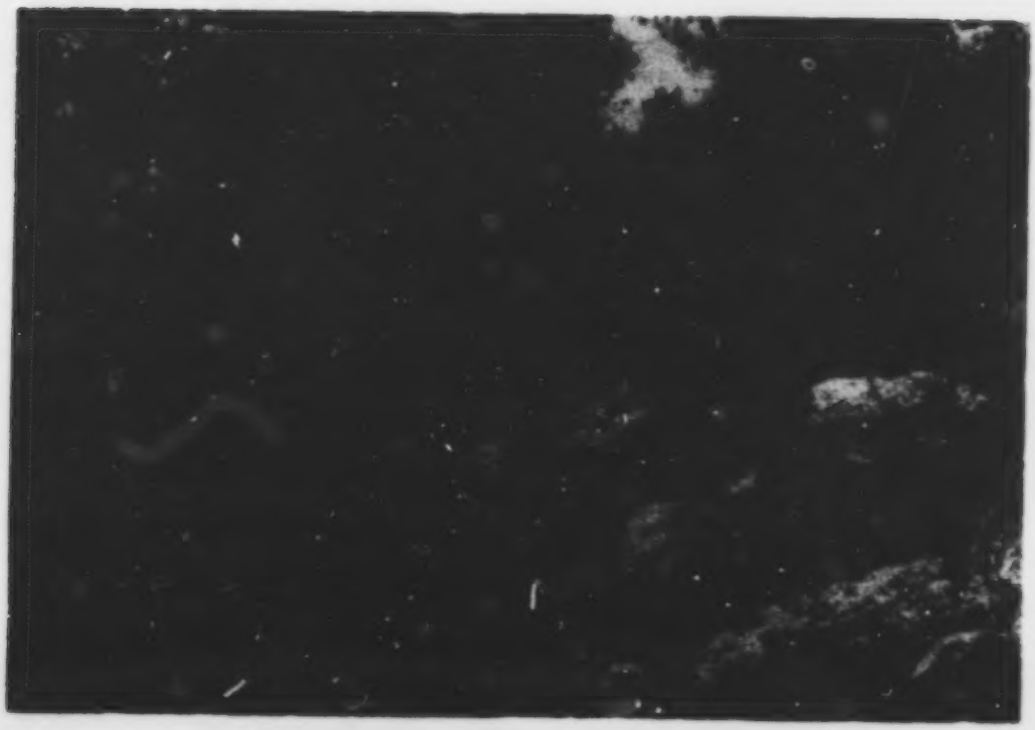

Plate 12. *Minor moraine near Harbo Lake (NTS 74 F-11). Note the steep side slope and the armour of sand-blasted boulders*

Plate 13. *Vertical aerial photograph, taken northwest of Carswell Lake (NTS 74 K-13), of minor moraines which developed near the ice front when it was in contact with Glacial Lake Athabasca*

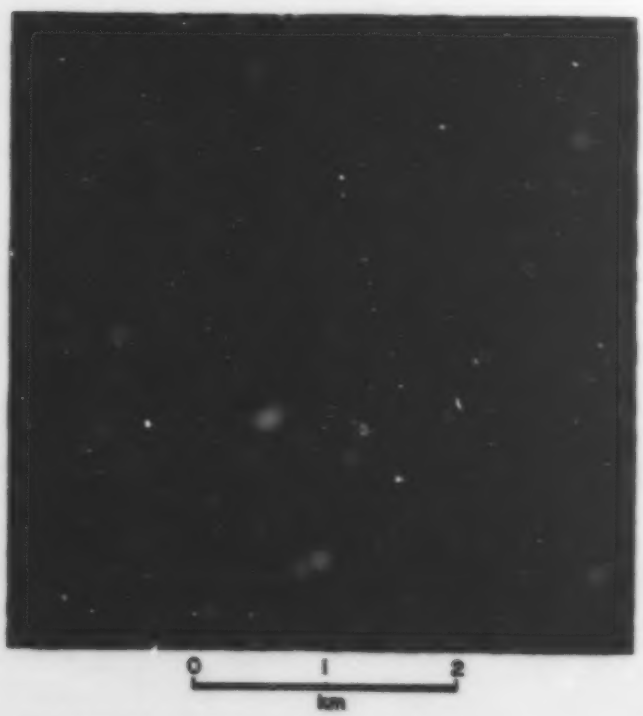

Plate 14. *Vertical aerial photograph, taken near the Williams River (NTS 74 K-14), of minor moraines which developed when the ice front was on dry land*

Plate 15. Large esker near the Geikie River that is partially braided, with kettles on the top and flanks of the ridge

Plate 16. Exposure in an extension of the esker in Plate 15, showing stratified sand, gravel and cobbles, near Wollaston Lake (NTS 64 L-4)

Plate 17. *Thick deposits of stratified sand in an ice-walled channel near Key Lake (NTS 74 H-4)*

Plate 18. *Kettles in a giant esker which marks a buried valley south of Deep Bay, Reindeer Lake (NTS 64 D-6)*

Plate 19. *Drumlins near Cree Lake (NTS 74 G-11). Ice advance was from the top right of the photo*

Plate 20. *Two till layers exposed in the nose of a drumlin near Key Lake (NTS 74 H-4)*

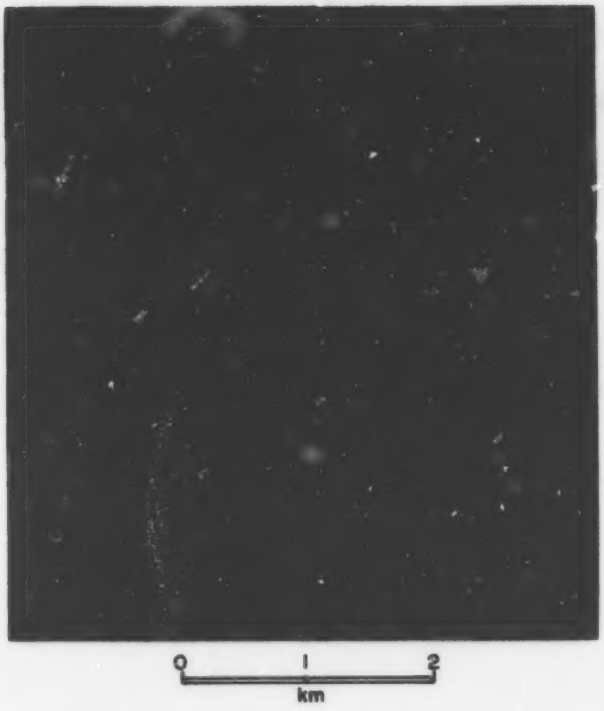

Plate 13. *Vertical aerial photograph, taken northwest of Carswell Lake (NTS 74 K-13), of minor moraines which developed near the ice front when it was in contact with Glacial Lake Athabasca*

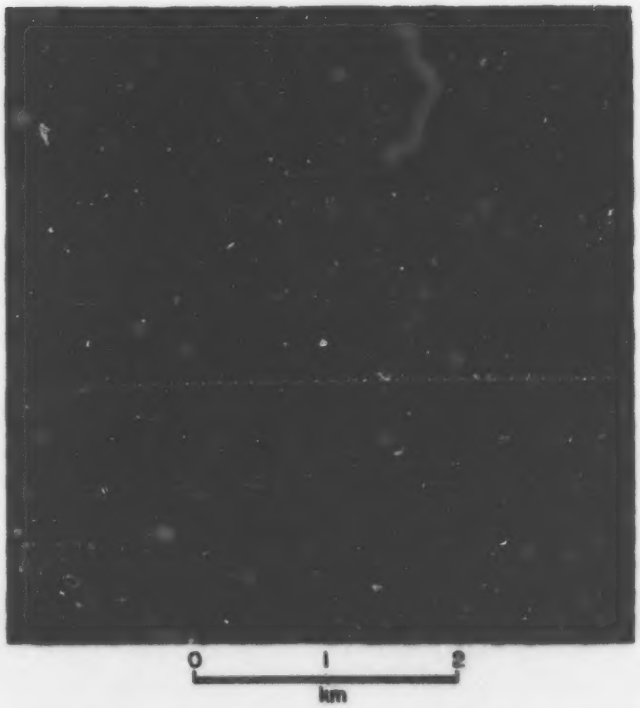

Plate 14. *Vertical aerial photograph, taken near the Williams River (NTS 74 K-14), of minor moraines which developed when the ice front was on dry land*

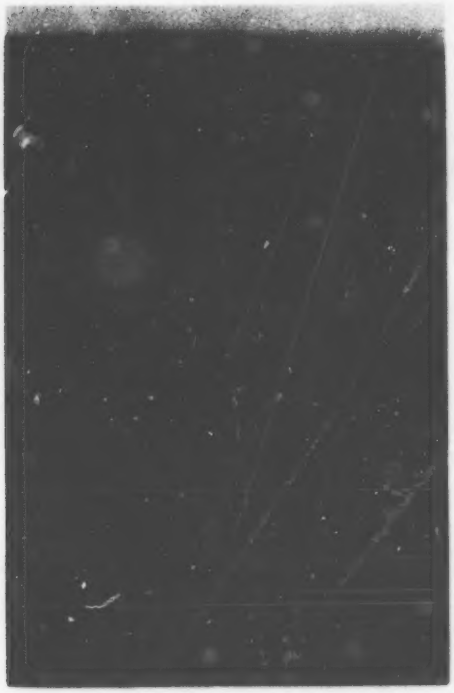

Plate 15. *Large esker near the Geikie River that is partially braided, with kettles on the top and flanks of the ridge*

Plate 16. *Exposure in an extension of the esker in Plate 15, showing stratified sand, gravel and cobbles, near Wollaston Lake (NTS 64 L-4)*

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Plate 19. *Drumlins near Cree Lake (NTS 74 G-11). Ice advance was from the top right of the photo*

Plate 20. *Two till layers exposed in the nose of a drumlin near Key Lake (NTS 74 H-4)*

Plate 21. *Close-up of area outlined in Plate 20. Thick, pink, sandy till with boulders and cobbles is overlain by sandy till and loose, very sandy till with boulders*

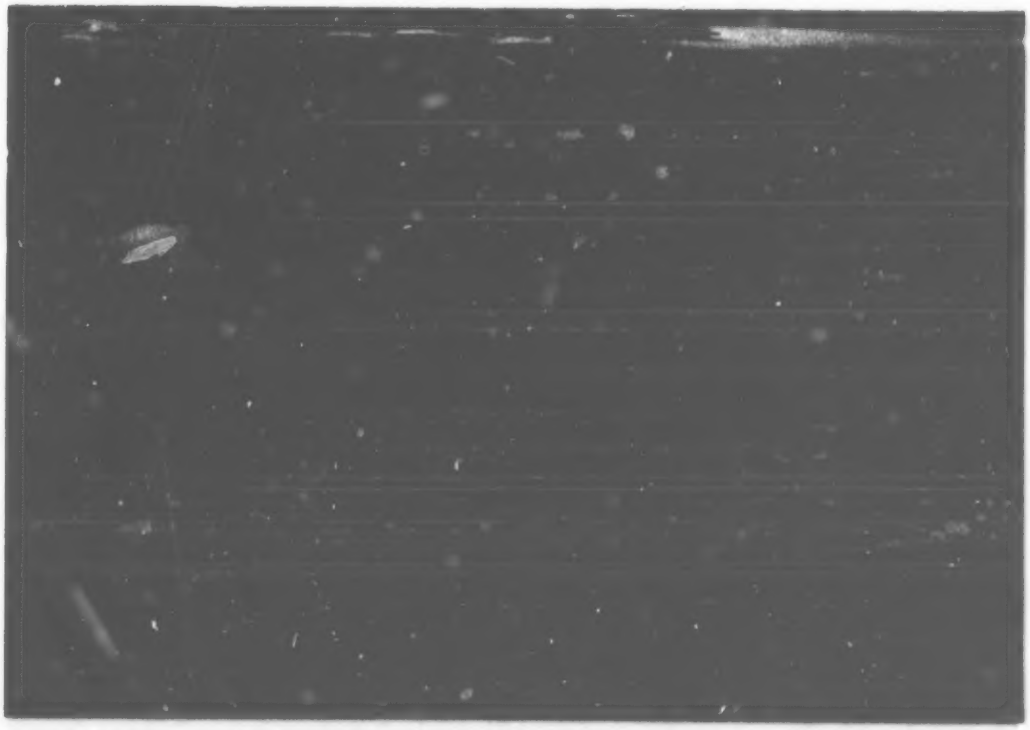

Plate 22. *Long, narrow ridges of till (ispatinows) near Catley Lake (NTS 74 G-11). They were formed, probably in a manner similar to drumlins, by glacial ice flowing from upper right to lower left in the photograph*

Plate 23. *Felsenmeer near a lake shore; large blocks of sandstone of a similar size covered with lichens*

Plate 24. *Felsenmeer on a hillside; cobble-sized angular blocks of sandstone with some lichen cover*

Plate 25. *Oblique aerial photograph showing wave-cut terraces of Glacial Cree Lake forming rings around a drumlin*

Plate 26. *Cobble beach of Glacial Cree Lake encircling the top of a hill north of Mayson Lake (NTS 74 G-14), at an elevation of about 35 m above present lake level*

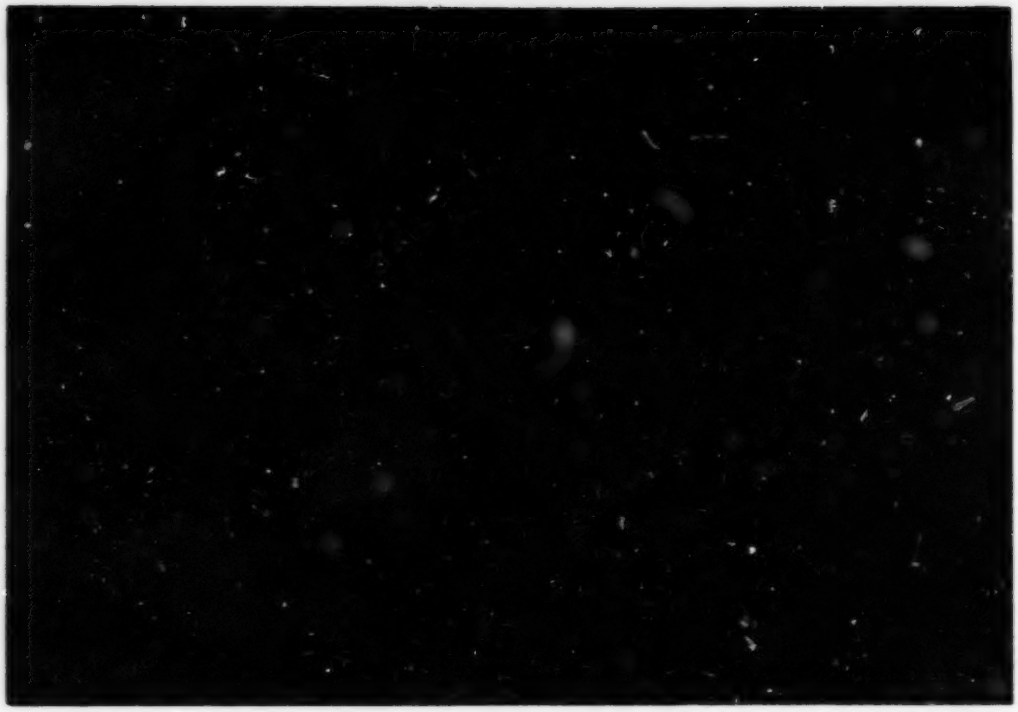

Plate 27. *Cobble beaches of Lake Athabasca, developed at about 1 m intervals, near Fish Hook Bay on Lake Athabasca*

Plate 28. *Cobble beaches of Glacial Lake Athabasca forming strandlines at an elevation of about 260 m near Riou Lake (NTS 74 O-1); terraces at 305 m lie to the right of the photograph*

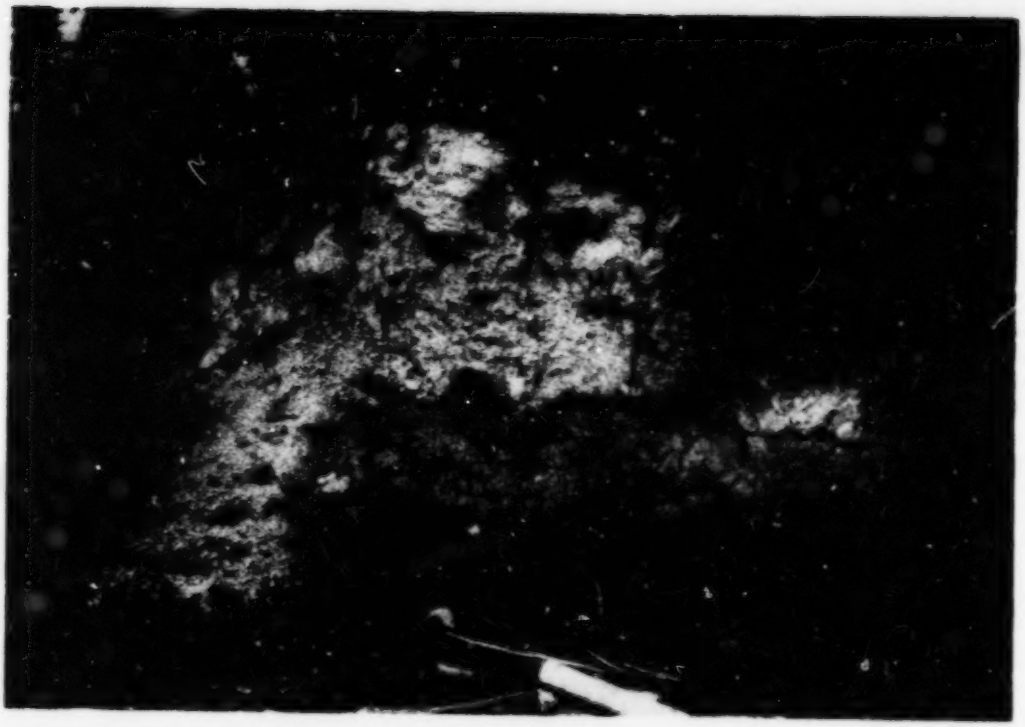

Plate 29. *Exposure of about 4 m of white, blocky silt of Glacial Lake Athabasca, located along the Fond du Lac River west of Stony Rapids*

Plate 30. *Mudjatik River meandering on the fill of the former glacial meltwater channel*

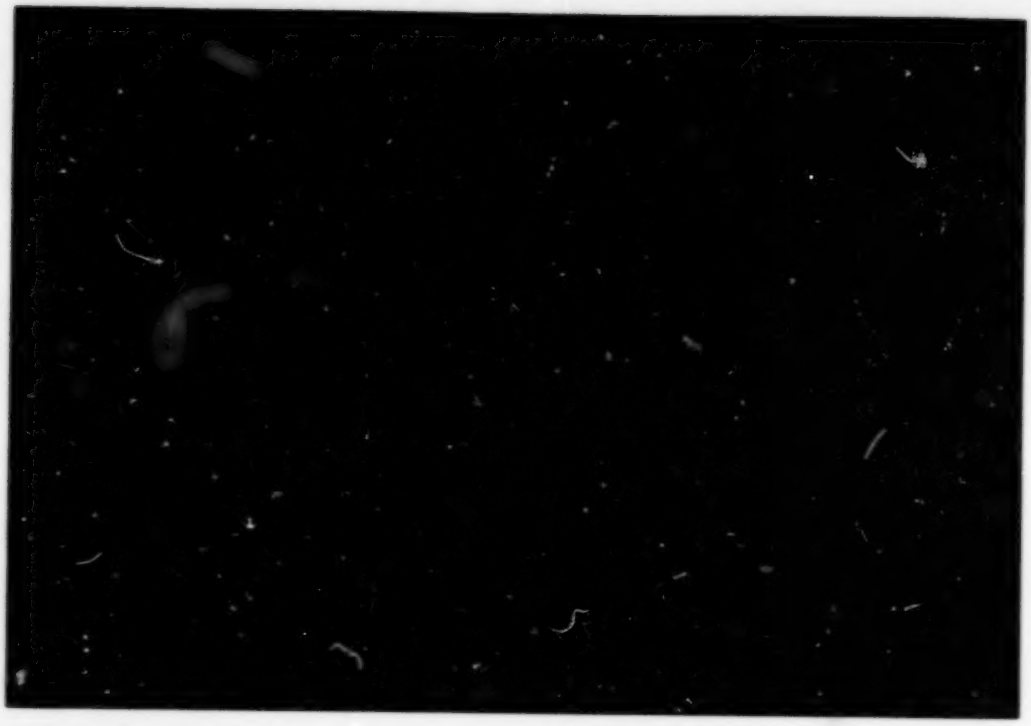

Plate 31. *The Clearwater River is deeply incised in Phanerozoic bedrock, exposing Precambrian basement rocks in places such as at the Contact Rapids*

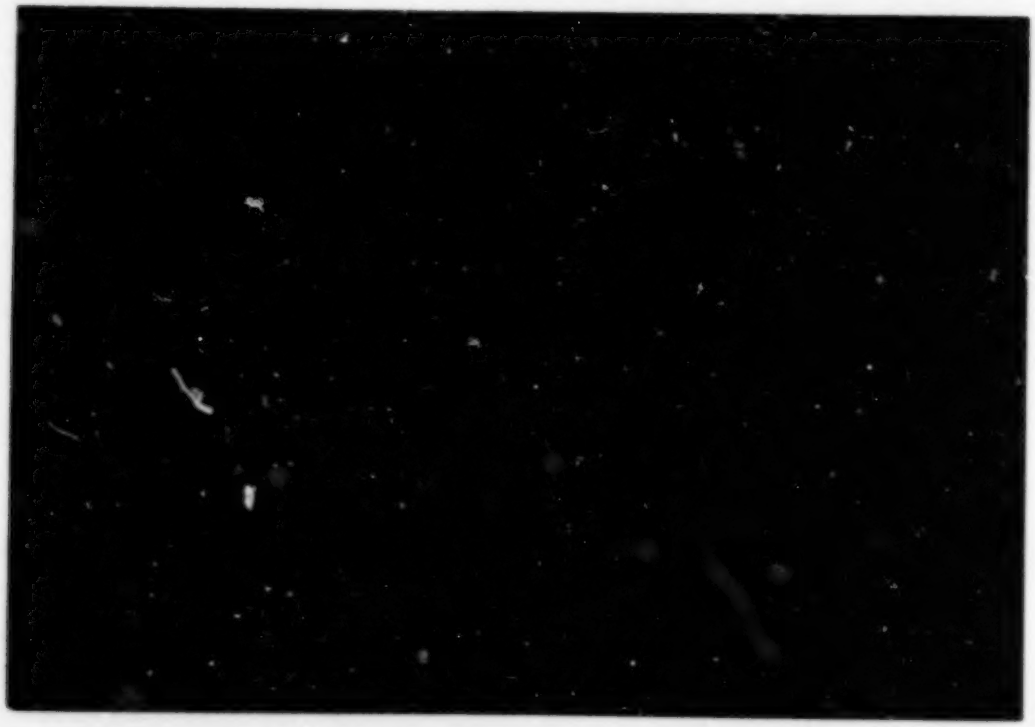

Plate 32. *A meander of the Clearwater River, showing sand bars in the river and point bars on the slip-off slope*

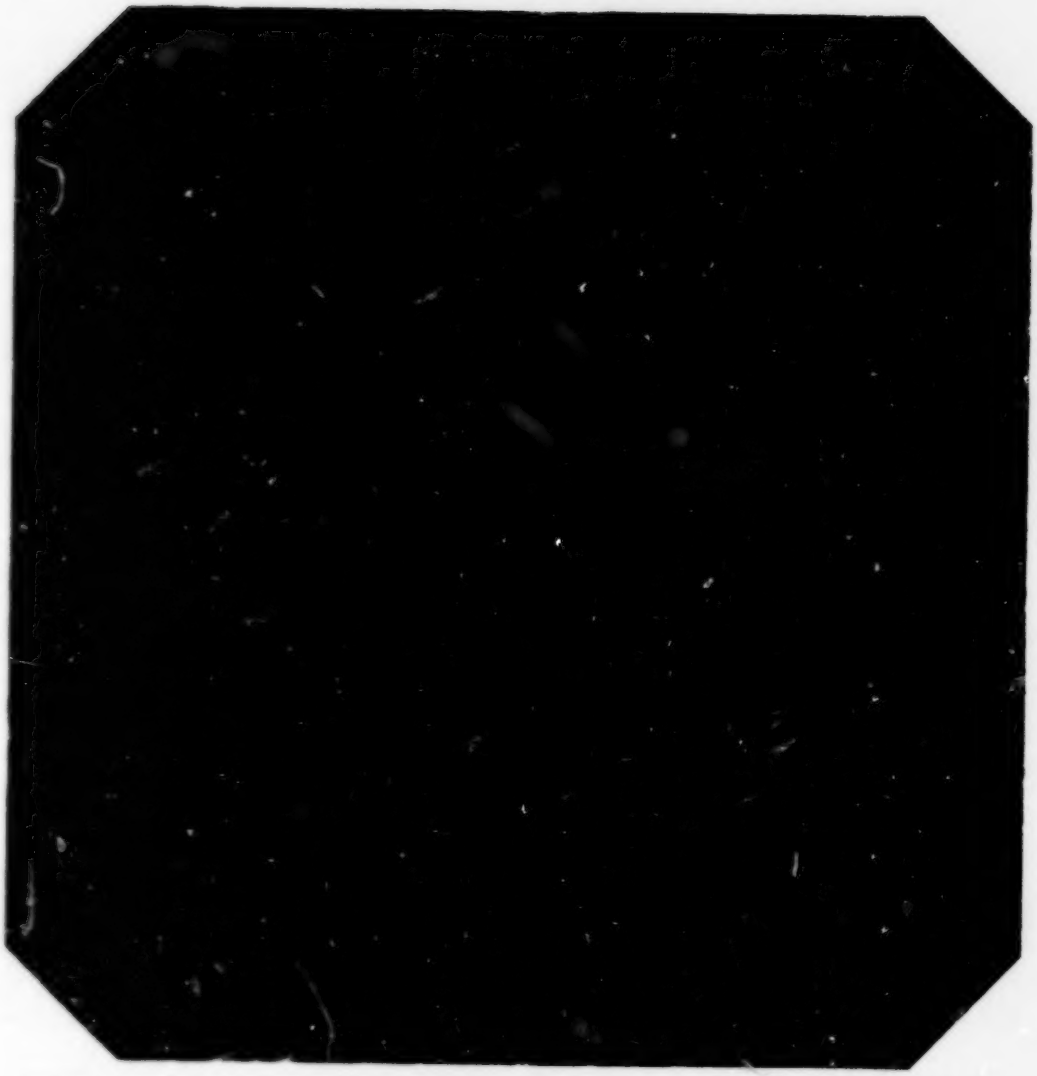

Plate 33. *Vertical aerial photograph of the Snare and McFarlane Rivers showing braiding and meanders on the fill of a former spillway. Broad sand plains occur in meander bends and where the channel enters small lakes or level areas. Note the eroded drumlins forming steep channel banks*

Plate 34. *An outwash plain in the Lloyd Lake area (NTS 74 F-7). A forest fire has removed most of the trees, revealing such features as the numerous kettles*

Plate 26. *Vertical aerial photograph of the William River delta on the south shore of Lake Athabasca (NTS 74 N-3). The sand forming the delta is transported by the river from the sand dune area to the west. Note the braiding in the river channel and the successive beach ridges*

Plate 36. Beaches, bars and sand spits in Costigan Lake (NTS 74 A-13)

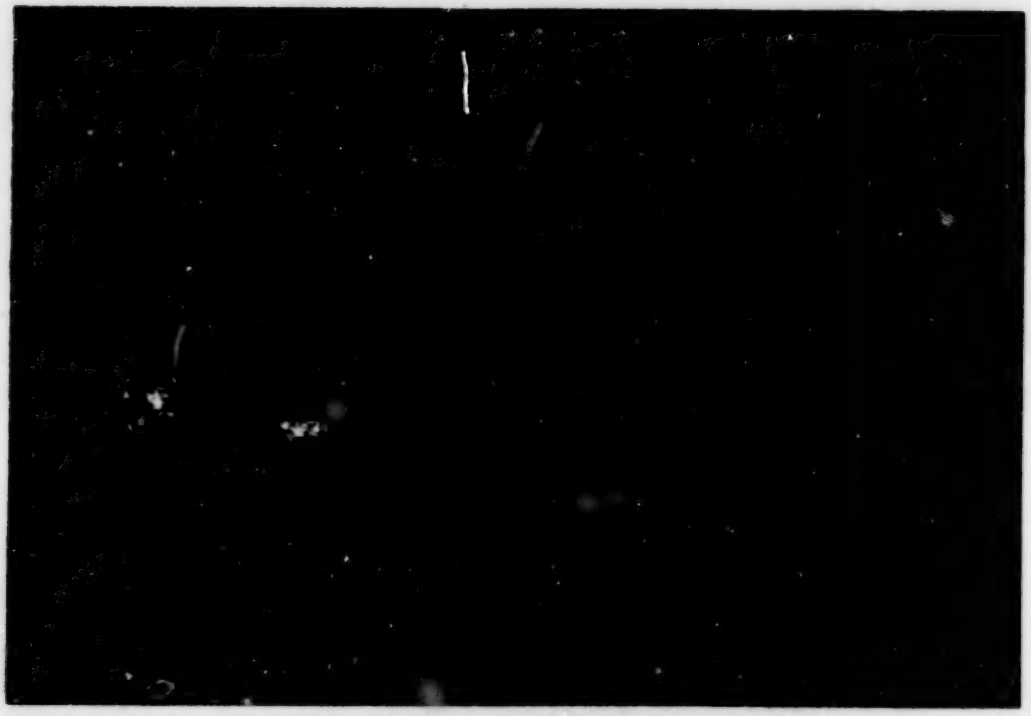

Plate 37. Long, arcuate sand beach on Costigan Lake (NTS 74 A-13)

Plate 38. *Lake rampart (a ridge of beach material pushed up on shore by expanding or shifting lake ice)*

Plate 39. *Muskeg south of the Shield margin (south of Amisk Lake (NTS 63 L-8)) containing patches of spruce in a sedge cover. Round lakes are characteristic of this area*

Plate 40. *Perched muskeg filling an isolated depression (at bottom of photo) enclosed by a bedrock ridge. During periods of high runoff, drainage is through a short valley to the river, which lies at a lower level. The river valley is also filled with muskeg*

Plate 41. *Muskeg (in centre of photo) occupying a low-lying area between drumlins in the Athabasca Basin. There are few perched muskegs in this area due to the subdued topography and good drainage*

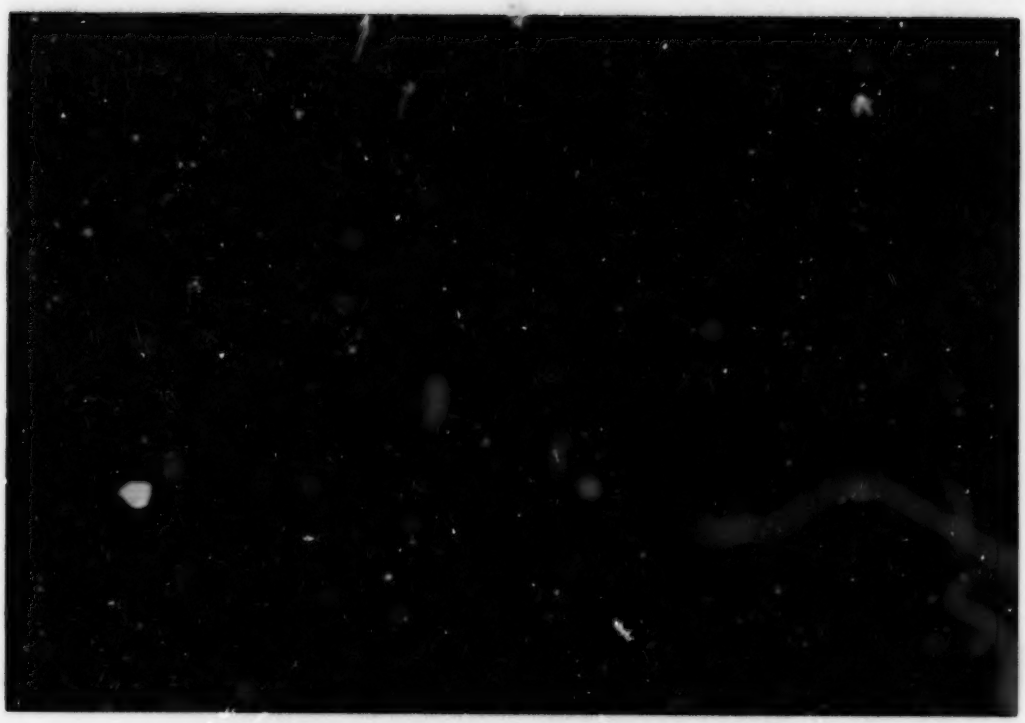

Plate 42. *Palsen in a muskeg near Descharme Lake (74 F-3)*

Plate 43. *Surface of a palsa rising above the water in a muskeg, located west of Hwy. 102 near the junction of Hwy. 105. Degrading permafrost has left a scarp of exposed peat*

Plate 44. *Close-up view of a palsa near Reindeer Lake, showing ice core and cover of peat*

Plate 45. *Fossil pingo in sediments of Glacial Lake Athabasca near Yakow Lake (NTS 74 N-1), caused by the expansion and contraction of an ice core during periglacial conditions*

Plate 46. *Frozen silt beneath a cover of moss, observed June 15, 1975 near Maribelli Lake (NTS 74 A-1)*

Plate 47. *Elongate, V-shaped, 'Cree Lake type' dunes (David, 1977a, b, 1981a) superimposed on older landscape features such as this braided esker in the William River area (NTS 74 K)*

Plate 48. *'Lake Athabasca embroidery pattern' dunes (David, 1977a) near the Cree River (NTS 74 G-16)*

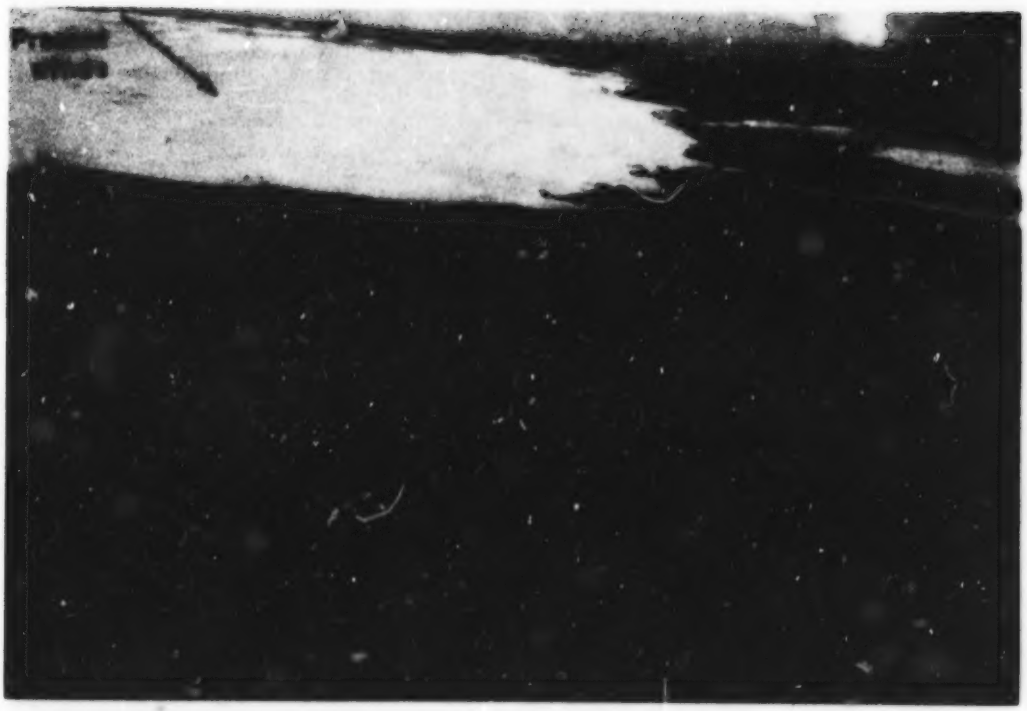

Plate 48. *Sand dunes south of Lake Athabasca near the mouth of the William River. The Cree Lake type dunes in the foreground, formed by southeasterly winds (David, 1977a), are older and have been anchored by vegetation. The active dunes in the background have been formed by northwesterly winds*

Plate 50. *Southeast-facing side of boulder etched and polished by sand-laden winds*

Plate 51. *Close-up of the boulder shown in Plate 50. Resistant grains, generally quartz crystals, protrude from the etched surface*

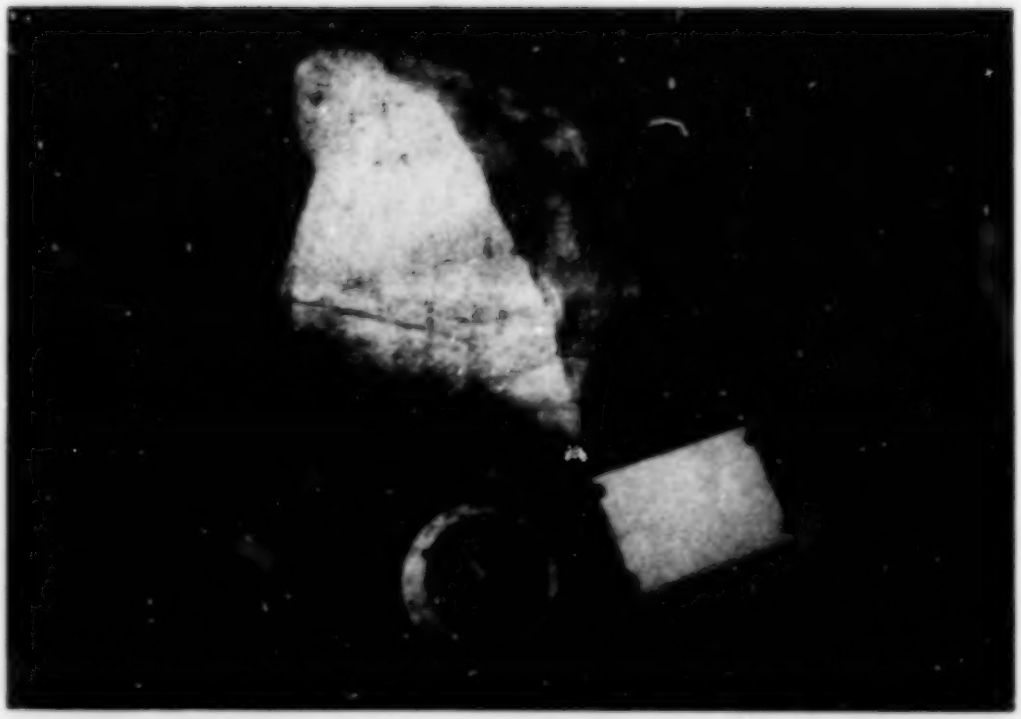

Plate 52. *Cobble etched and polished by sand-laden winds, indicating wind directions from the southeast and northwest*

Plate 53. *Very sandy till exceeding 35 m in thickness. Colour changes from yellowish-brown at surface to pinkish-grey at depth*

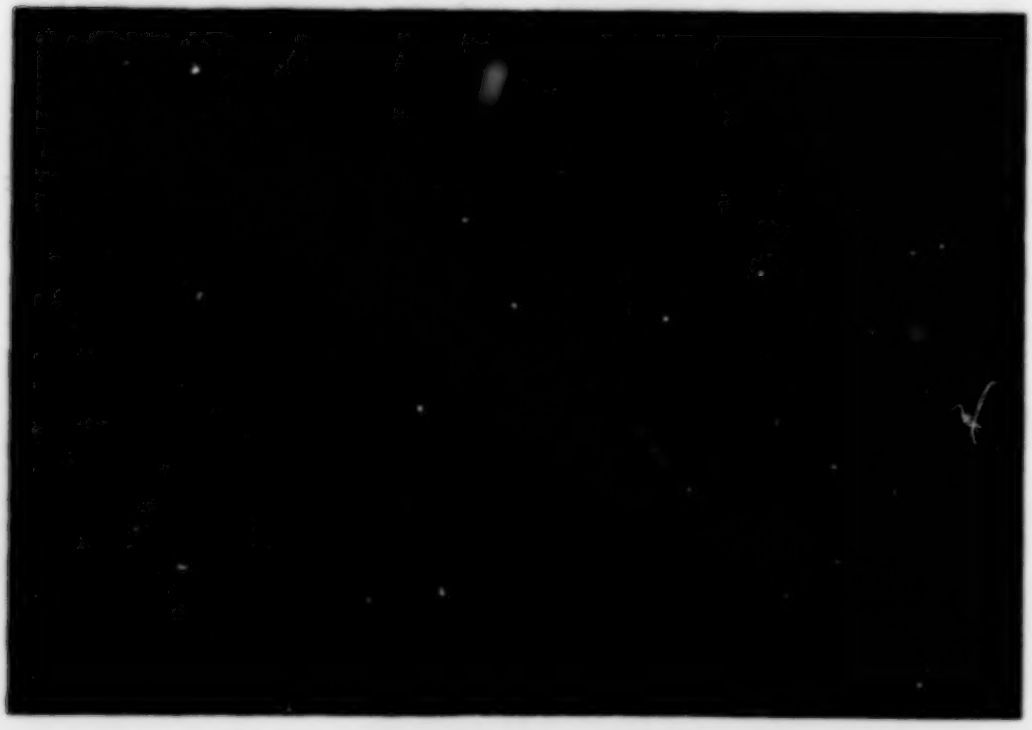

Plate 54. *Very sandy till containing subangular to subrounded pebbles and cobbles (scale in centimetres)*

Plate 55. *Yellowish-brown sandy till derived from Precambrian basement rocks and showing abundant angular to subangular boulders*

Plate 56. *Variation in fine sediments of Lake Agassiz from thick flay-lying varves at the base through thin contorted varves to massive amorphous clay at surface. The deformation is caused by freezing and thawing cycles (congeliturbation)*

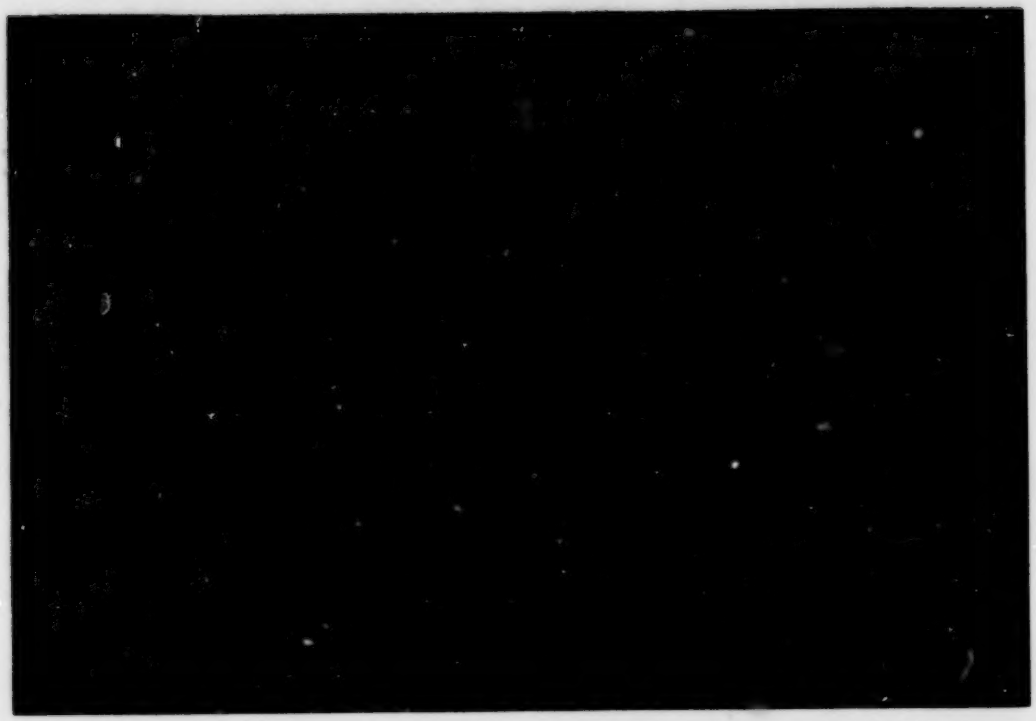

Plate 57. *Oblique aerial photograph of the Saskatchewan River Delta near Cumberland House. The main channel in the centre of the photo is flanked on each side by meandering distributaries*

Plate 58. *Partially frozen peat just east of Uranium City. This exposure reveals brown fibrous peat at the surface grading downwards into black gyttja which is frozen. Note the brown fibrous lenses of peat in the frozen, more decomposed section*

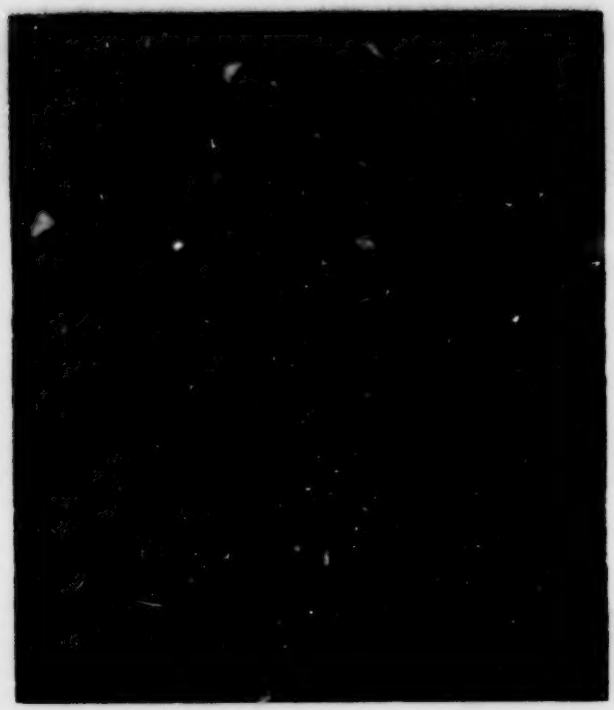

Plate 58. *Multiple till sequence in an exposure (BS-1730) located 6.5 km north of Otter Rapids (NTS 73 P-10)*

Plate 59. *Close-up of the hard, compact, silty sand till shown in Plate 58*

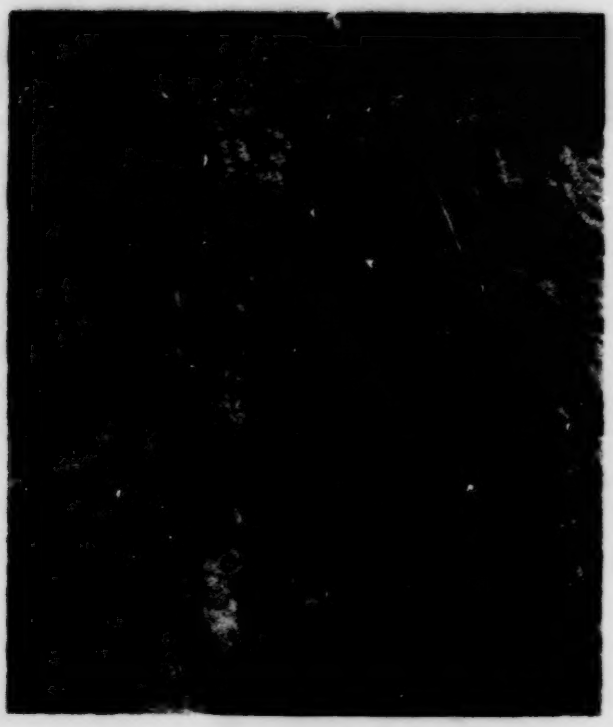

Plate 61. *Multiple till sequence in an exposure (BS-1732) located 1.5 km north of Otter Rapids (NTS 73 P-10)*

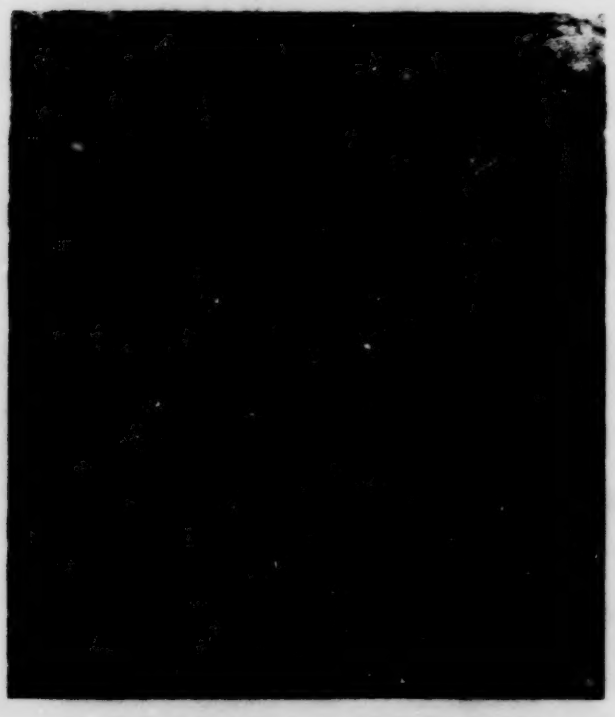

Plate 62. *Close-up of till sequence shown in Plate 61*

Plate 63. *Hard, grey, sandy lodgement till overlain by soft, brown, sandy ablation till which is sporadically covered by a thin layer of eolian silt, on Hwy. 105 at Hidden Bay, Wollaston Lake (NTS 64 L-4)*

Plate 64. *Thin till overlying gravel at site BS-877 on Hwy. 135 north of Pelican Narrows*

Plate 66. *Thin till overlying stratified silt and gravel at site BS-2 on Hwy. 2 about 10 km south of Missinipe*

Plate 68. *Ice-contact deposits consisting of intermixed, poorly stratified gravel, sand, silt and till, on Hwy. 102 north of McLennan Lake*

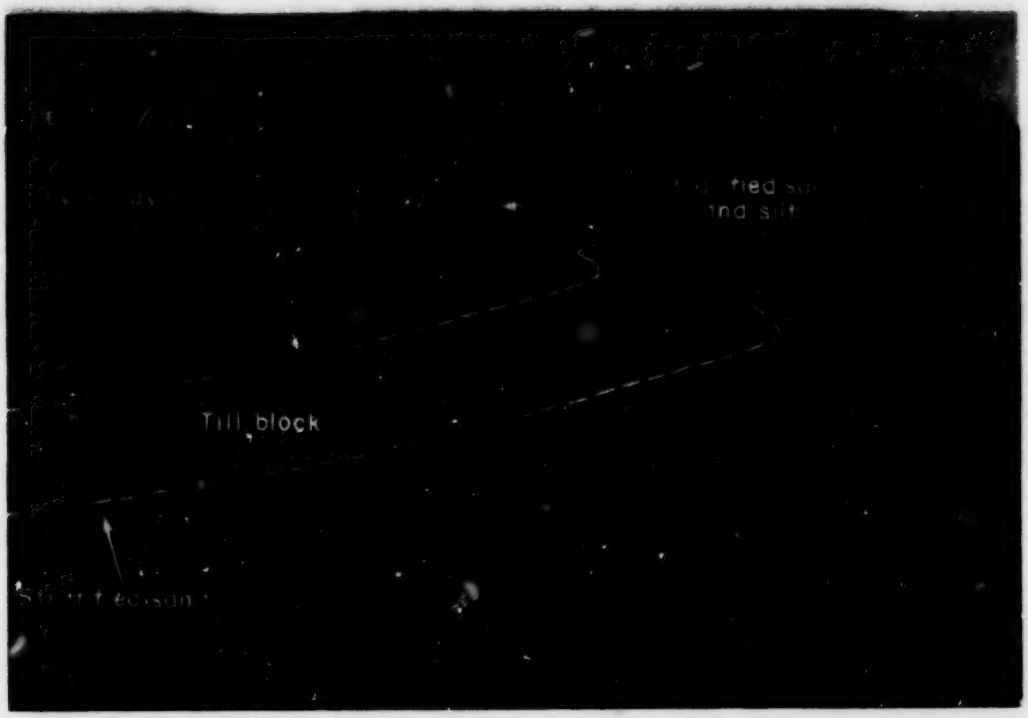

Plate 67. *Stratified gravel, sand and silt containing a large block of massive till and overlain by thin sandy till, located in a borrow pit east of Hwy. 2 on the road to Stanley Mission*

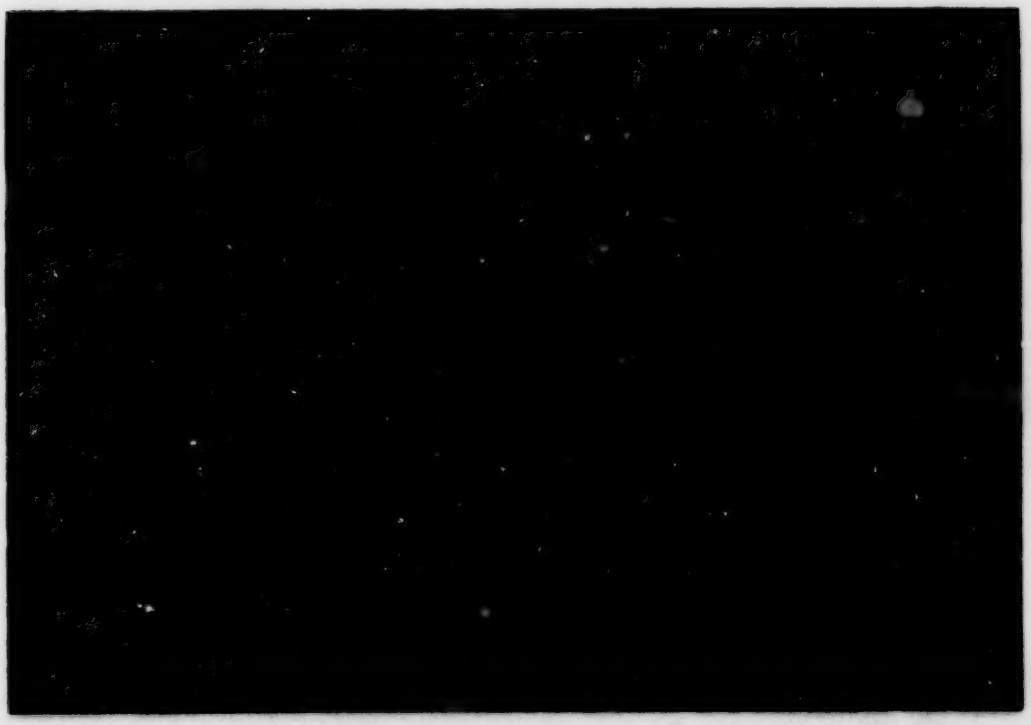

Plate 68. *Coarsely stratified sand and gravel containing cobbles and boulders, deposited by meltwater in a bedrock valley east of Uranium City*

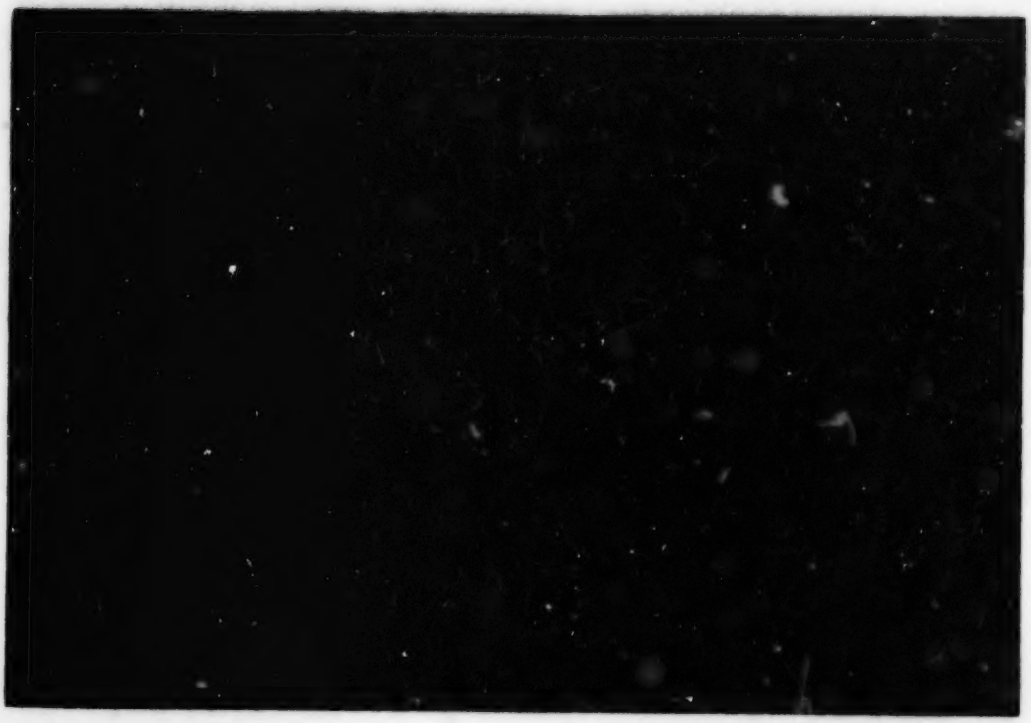

Plate 69. *Well-stratified sand deposited in forset beds where meltwater entered Glacial Lake Athabasca. This exposure near Uranium City is approximately 90 m above the present lake level*

Plate 70. *Well-stratified fine sand and silt exposed along the banks of a creek on the Black Lake road (NTS 74 P-4)*

Plate 71. Exposure of well-stratified fine sand near the William River (NTS 74 N-3)

Plate 72. Close-up of exposure shown in Plate 71, containing ripple marks and cross-bedding

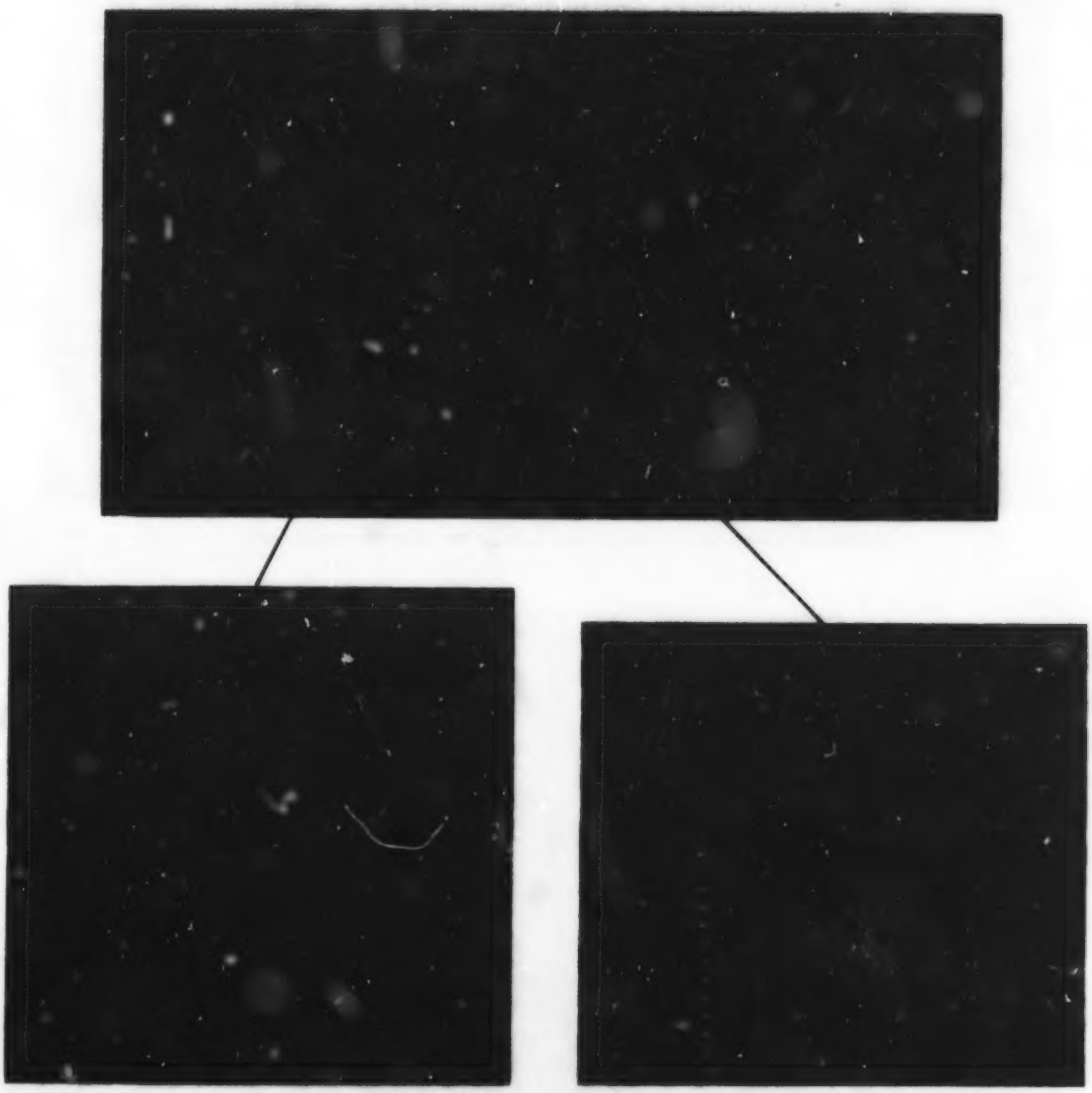

Plate 73. *Transgressive onlap ('fining upward') sequence in Lake Agassiz sediments near Brabant Lake (NTS 64 D-4). Fine sand at the base is overlain by thick, sandy, varved silt. The varves are thin and contorted higher in the section and grade upward into massive silty clay. Scale in centimetres*

Plate 74. *Fine sand overlain by silt and silty clay in an exposure of Glacial Lake Athabasca sediments along the Black Lake road (NTS 74 P-4)*

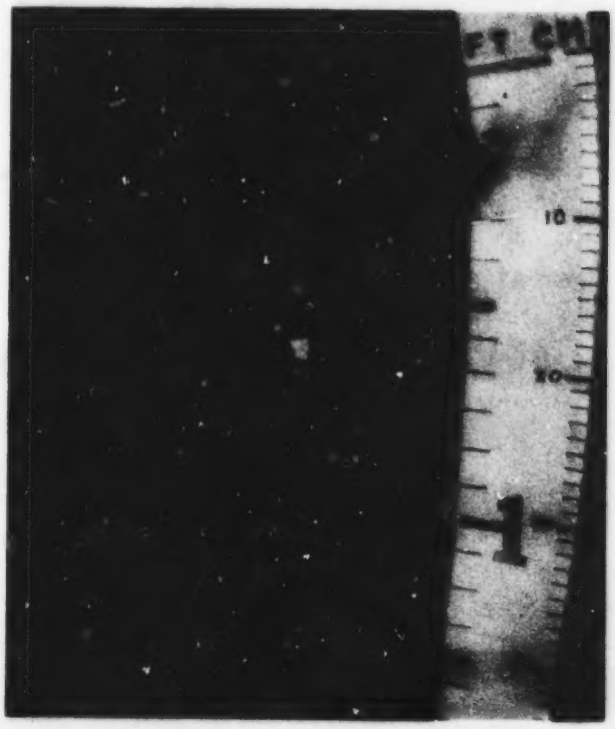

Plate 75. *Typical degraded Dystric Brunisol*

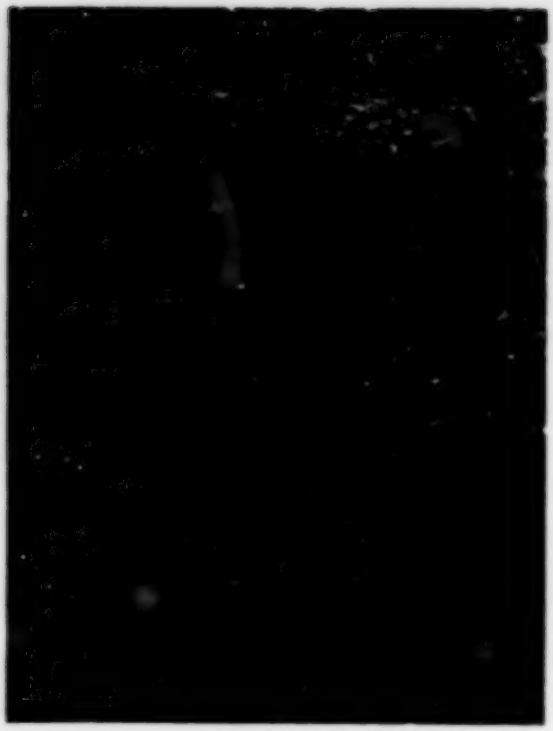

Plate 76. *Typical Humo-Ferric Podzol*

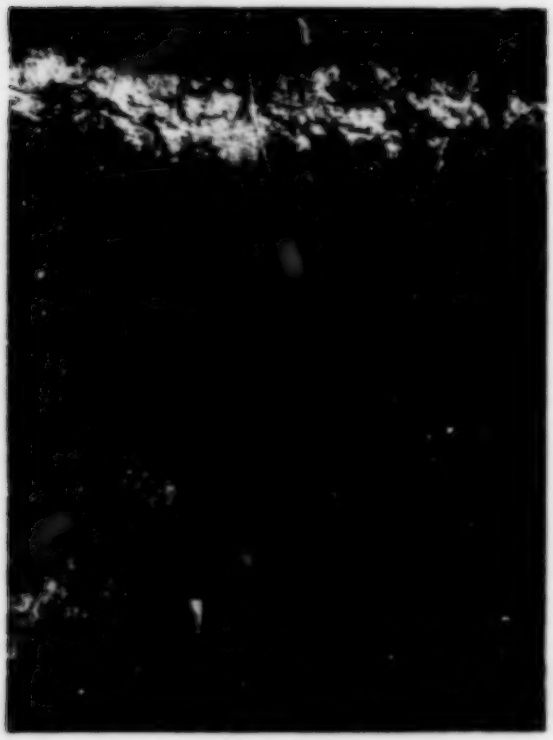

Plate 77. *Typical Orthic Grey Luvisol*

MAPS NOT

FILMED

CARTES

OMISES

POOR

QUALITY

ORIGINAL